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OAR RESEARCH REVIEW

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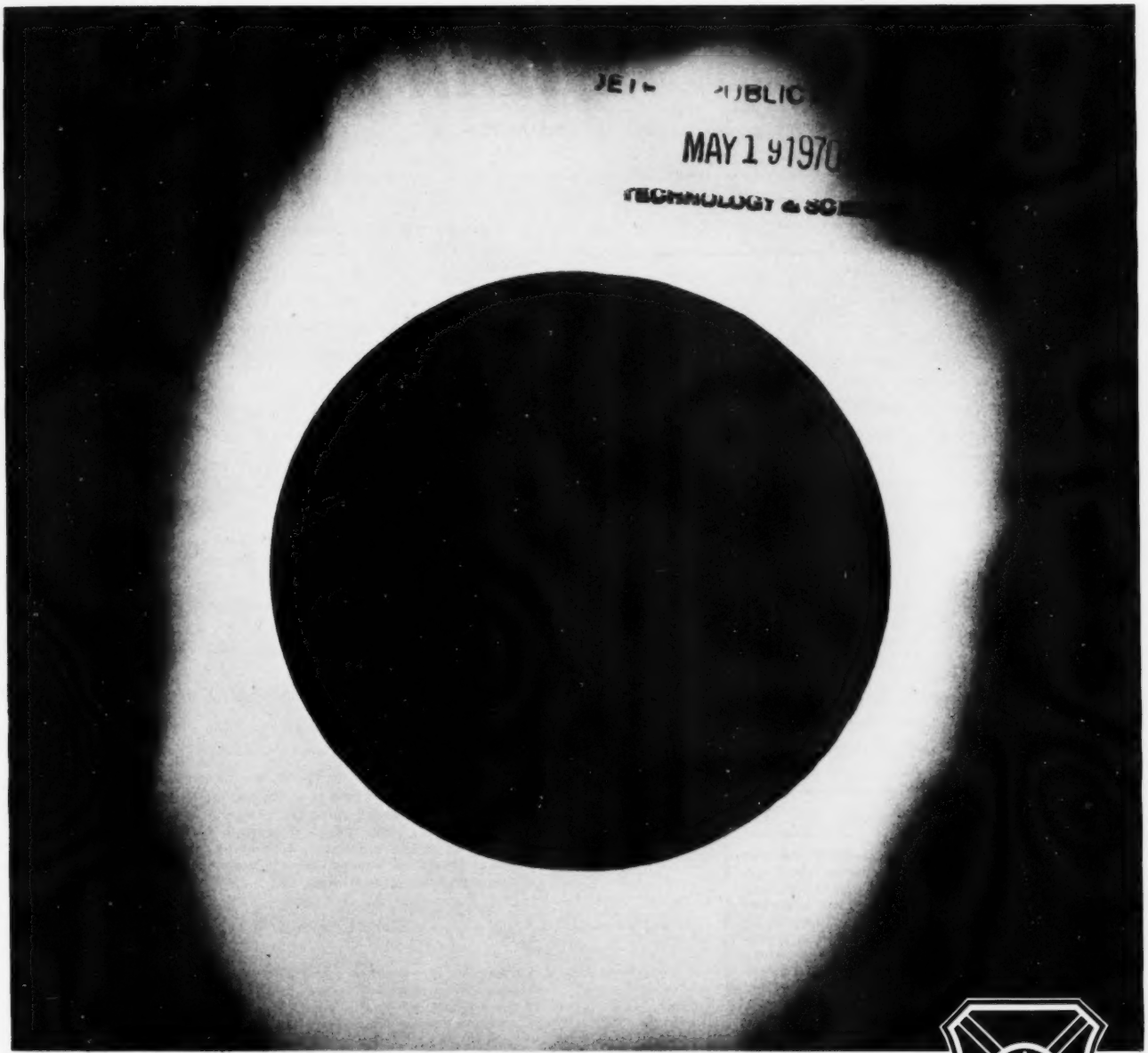

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OFFICE OF AEROSPACE RESEARCH

OAR RESEARCH REVIEW

VOLUME IX NUMBER 2 MARCH-APRIL 1970

ON THE COVER:

More than 50 AFCRL scientists observed the March 7, 1970 solar eclipse which cut across Mexico, the Gulf Coast region, and up the Eastern seaboard. It was observed from many locations with a variety of instruments. Two AFCRL KC-135 flying laboratories had more than 15 scientists aboard. The Eglin Test Range in Florida fired seven rockets and the range at Wallops Island, Virginia, fired three rockets. Also, ground observations were made at AFCRL's Radio Astronomy Observatory at Hamilton, Massachusetts, and at special field sites in Virginia, Florida, Massachusetts (Cape Cod), and Mexico. Most AFCRL observations concerned the effects of eclipse-induced changes in the ionosphere on radio and optical sensors.

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ETHEL GAMER *Editor*

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table of contents

PLASMA-FLOW FACILITY	4	P. W. Schreiber and Maj K. H. Schumaker, Thermomechanics Research Laboratory, ARL, and K. R. Benedetto, Systems Research Laboratories, Inc., Dayton, Ohio
RESEARCH IN STOCKHOLM ON ION IMPLANTATION IN SEMICONDUCTORS*	7	Major Lawrence B. Molnar, EOAR
ELASTIC PROTON SCATTERING	9	Dr. Jose C. Manthuruthil, General Physics Research Laboratory, ARL
ADDITIVES—A SEARCH FOR UNDERSTANDING	13	Robert L. Tischer, Chemistry Research Laboratory, ARL
EMISSION FROM EXCITED TERMINAL STATES OF BOUND EXCITON COMPLEXES	15	Donald C. Reynolds, Director, Solid State Physics Research Laboratory, ARL
DO OPTICAL PHOTONS INTERFERE ONLY WITH THEMSELVES?	17	Dr. Leonard Mandel, The University of Rochester
CHEMICAL MODIFICATION OF IGNITION TEMPERATURES	20	M. E Morrison and Dr. K. Scheller, Chemistry Research Laboratory, ARL
NONPARAMETRIC TECHNIQUES IN STATISTICAL INFERENCE	23	Maj William R. Trott, Directorate of Mathematical Sciences, AFOSR
THE BOUNDARY-LAYER TRANSITION MAZE	24	Kenneth F. Stetson, Fluid Dynamics Facilities Research Laboratory, ARL
CANINE HIP DYSPLASIA	27	Dr. George H. Cardinet, III, D.V.M., Neuromuscular Research Laboratory, College of Veterinary Medicine, Kansas State University, Kansas
BIG JETS AND AIRPORT METEOROLOGICAL INSTRUMENTS	30	Aerospace Instrumentation Laboratory, AFCRL
NEW LUNAR LASER OBSERVATORY PLACED IN OPERATION	31	Terrestrial Sciences Laboratory, AFCRL
USE OF LIGHT PRESSURE TO MEASURE WEIGHT	33	Space Physics Laboratory, AFCRL
LARGE CUPROUS-CHLORIDE CRYSTALS PROMISE TO ADVANCE LASER MODULATION	35	Solid State Sciences Laboratory, AFCRL
NEW METHOD FOR COMMUNICATING THROUGH THE PLASMA SHEATH	37	Microwave Physics Laboratory, AFCRL
CORRECTING IONOSPHERIC EFFECTS IN RADIO RANGING AND NAVIGATION	38	Ionospheric Physics Laboratory, AFCRL

PLASMA FLOW FACILITY

P. W. SCHREIBER and MAJOR K. H. SCHUMAKER, Thermomechanics Research Laboratory, ARL and K. R. BENEDETTO, Systems Research Laboratories, Inc., Dayton, Ohio

Plasma flow plays an important role in the development of numerous Air Force systems, such as high-intensity radiation sources, high-energy re-entry simulation facilities, wind-tunnel heaters, and propulsion devices. Basic plasma properties and diagnostic techniques are needed to design and evaluate these systems. In order to aid in the accomplishment of these tasks and add to the knowledge of plasma flow, an arc plasma-flow facility was developed at the Thermomechanics Research Laboratory, ARL.

Because the attainment of reliable research results depends strongly on the establishment of a stable laminar flow, the arc discharge described in this report was first studied by employing a quartz tube, and high-speed photographic and photoelectric techniques. From this study it was found that laminar conditions exist at low mass-flow rates and a developing region was clearly observed as theoretically predicted. (1) However, observations indicate that, as the mass-flow rate is increased, the flow becomes turbulent.

The laminar flow regime is presently being investigated and defined. For this study the arc source is being used to develop diagnostic techniques and to determine basic thermodynamic and transport properties of gases of interest to the Air Force. After this research is completed, the turbulent case will be studied.

The plasma-flow facility consists of a long, wall-stabilized, electric arc; high d-c power supplies; a system to store gases and measure flow rates; an automatic control console; and diagnostic equipment such as probes, spectrometers, radiometers, and lasers. In order to facilitate optical measurements, the arc is mounted vertically on a slide mechanism, and the entire assembly is mounted on a hydraulic scissors table. This arrangement allows the discharge to be aligned with the optical instrumentation.

The arc column consists of 90 copper segments as shown in Figure 1. Each segment is 1 cm thick, with a 1-inch diameter bore and a 3-inch outer diameter. The copper segments are insulated from each other by phenolic rings which are shielded from the arc radiation. The separation between each segment is approximately 0.003 inch. The discharge may be pulsed for approximately 2 seconds without external cooling. After a run, the segments are cooled to their original temperature in order to duplicate the initial conditions. A typical section and a phenolic insulator are shown in Figure 2. By not including complex cooling passages for continuous operation, the cost of the segments and associated equipment is greatly reduced.

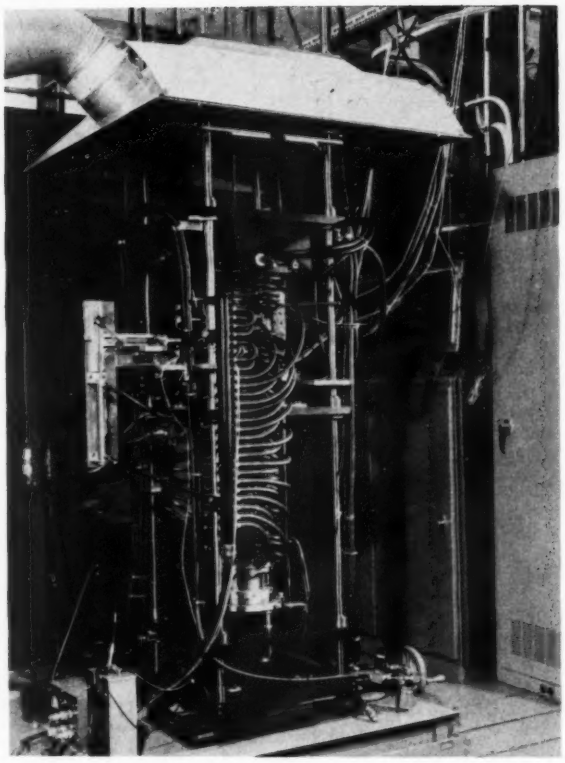

Figure 1. Wall-stabilized arc showing probe traversing mechanism.

A computer program was used to design the arc segments for pulsed operation. (2) Arc characteristics

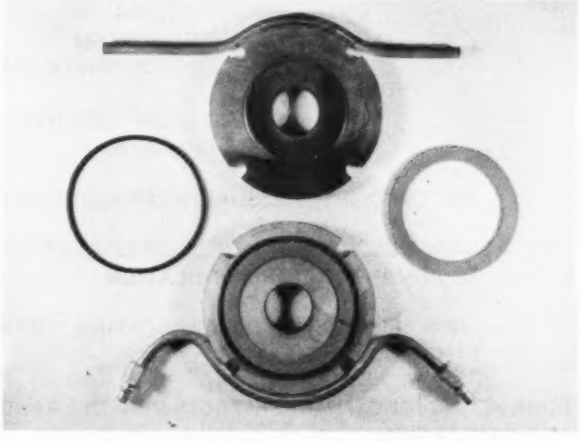

Figure 2. Copper constrictor segments for the pulsed, wall-stabilized arc discharge showing the O-ring sealer and the insulating ring.

(voltage gradient vs. current) were computed and used to estimate the power input into a segment. Using these data and the thermal properties of copper, the time temperature history of the inner wall was calculated for maximum power conditions. These results indicated that several seconds were required before the copper wall reached melting temperature. In addition, the calculated voltage drop across one segment was too small to form a secondary cathode and anode. Arc tests proved that these calculations were adequate to design uncooled segments for pulsed discharges.

Preliminary tests with water-cooled copper anodes indicated that an individual anode (without forced spot motion) can carry approximately 500 amperes without seriously reducing its lifetime. For this reason, 4 independent anodes are used to extend the current capabilities of the arc discharge. This is achieved by connecting each anode to a separate power supply so that the current may be distributed evenly among them. The corresponding cathode consists of a water-cooled, thoriated-tungsten tip which may be operated from 300 to 2,000 amperes. This electrode is accurately centered in the lower end of the arc column.

The mass-flow rate of gas is measured by a system of calibrated sonic nozzles. The flow is introduced into a plenum chamber at the cathode end of the arc. In order to eliminate or reduce longitudinal oscillations associated with the organ-pipe effect in straight flow, the plenum chamber

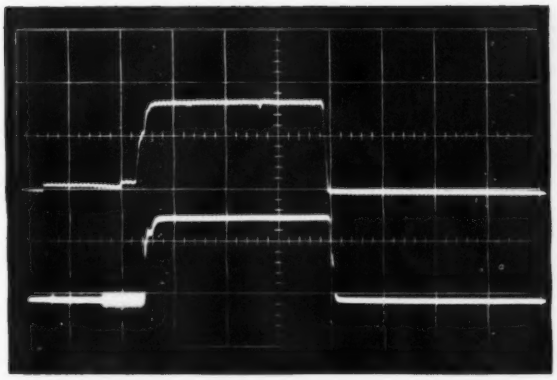

Figure 3. Arc current and voltage as a function of time: upper trace arc current (510 amp/cm); lower trace arc voltage (300 volts/cm); sweep speed: 0.2 sec/cm.

is filled with quartz wool. With the quartz wool removed, the same chamber may be used as a vortex generator to provide vortex stabilization of the arc column, thereby allowing the wall-stabilized arc to be compared directly with a vortex-stabilized arc.

The total d-c power available for operating the arc discharge is two megawatts. Various output characteristics may be achieved by series-parallel combinations of the individual supplies. In order to reduce the ripple content

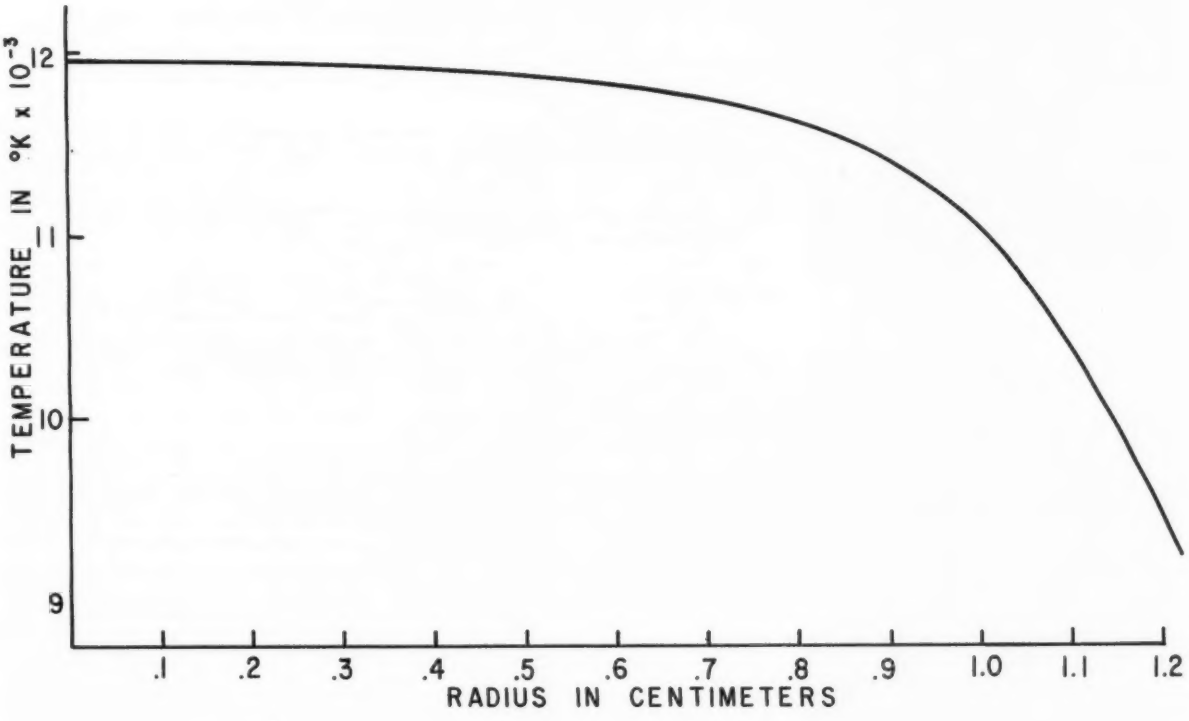

Figure 4. Temperature distribution in 1-inch-diameter arc discharge operating at 730 amperes.

from the three-phase, full-wave rectifiers, a series inductor is used. With this system, the ripple is less than one percent. Typical voltage and current traces are shown in Figure 3.

The arc is started by contracting a pneumatically driven anode starter with the cathode tip. A resistor is connected in series with the starter anode in order to limit the starting current. The starter is withdrawn in 50 milliseconds, and the arc re-attaches to the main running anodes as the starter passes them. Shortly after starting, additional power supplies are activated until the desired current level is achieved. A motor-driven, automatic cam controller is used to sequence the various events during the operation. At preset time intervals, starting, the addition of power, the triggering of data-acquisition systems, and shutdown occur. The duration of the high-current pulse is on the order of 1 second.

Diagnostic instrumentation included in the facility is used to measure the total current and voltage, voltage gradients, temperature and radiation distributions, total radiation per unit arc length, self-magnetic field distributions, wall-heat flux, static pressure gradients, and stagnation pressure distributions. Probe measurements are accomplished by using the traversing mechanism shown in Figure 1. This mechanism allows a probe to be inserted and withdrawn from the plasma in a period of approximately 20 milliseconds. Voltage-gradient, stagnation-pressure, and magnetic-field probes are used with this mechanism. (3,4) In addition, a high-speed enthalpy probe will be designed and fabricated by the Cornell Aeronautical Laboratory for use with this mechanism. (5) Optical measurements are made through optical ports which allow complete distributions to be measured in a direction lateral to the discharge axis. Arc radiation is focused on the entrance slit of a grating spectrometer and/or a thermistor detector by an optical system employing a rotating mirror. Thus, spectral as well as total radiation lateral distributions may be obtained in a single operation and the data reduced to radial distributions. In order to reduce reflection errors, total radiation data are normalized to thermocouple measurements of total radiation per unit arc length achieved without the use of mirrors. Instrument calibration is achieved by making direct comparisons with standards of total and spectral radiation obtained at NBS. Data reduction is facilitated by recording probe and radiation output data directly as a function of

SCHREIBER

SCHUMAKER

Mr. Paul W. Schreiber is a Group Leader of the High-Temperature Plasma Diagnostics Work Unit in the Thermomechanics Research Laboratory, ARL. He has been with ARL since 1961, and has conducted research concerned with the application of experimental and theoretical plasma physics to electric arcs. This work includes the developing of experimental and analytical techniques to determine the spatial distributions of emitted and absorbed radiation, current density, electron density, enthalpy, and velocity in high-pressure and high-temperature electric discharges.

Mr. Schreiber received his B.S. degree from the University of Dayton in 1950, and his M.S. from Ohio State University in 1956. He was an instructor at AFIT from 1950 to 1954. For his work at ARL, he received the Outstanding Performance Award in 1967 and 1968. He has about 20 publications to his credit.

Major Karl H. Schumaker has been Deputy Director of the Thermomechanics Research Laboratory, ARL since 1967. He is currently engaged in research on the diagnostics of high-temperature and high-pressure arc-plasma discharges, with particular concentration on the determination of transport properties, temperature-distribution profiles, and energy balances in arc discharges at pressures to 1,000 atm.

Major Schumaker received his B.S. in Electrical Engineering from the University of Detroit in 1956, and his M.S. in Nuclear Engineering from AFIT in 1961. He has completed all requirements for the Ph.D. in Engineering Applied Science at the University of California, Davis-Livermore, and at present is working on his dissertation. In 1956, upon graduation from Detroit University, he received a commission as 2nd Lieutenant in the USAFR. He came on active duty in March 1957. His assignments have included ATC, TAC, AU, AFSC, and OAR.

Major Schumaker is a member of Tau Beta Pi, Eta Kappa Nu, and RESA. He has several publications to his credit.

lateral position. This is achieved by using appropriate transducers on the traversing mechanism and the rotating mirror.

The major advantages of this facility are:

1. The large diameter allows probes to be directly inserted into the plasma without seriously disturbing the original plasma state.
2. The temperature profile is essentially flat over a large part of the arc diameter Figure 4.
3. The long arc length assures that developed conditions are achieved.
4. The developing region may be investigated.
5. Stable laminar conditions are achieved for low flow rates.
6. The facility may be used to study instabilities and turbulent flow.
7. Vortex stabilization may be compared directly with wall stabilization.
8. Basic data may be reduced in a simple way to yield transport properties. (4)

Future plans include the development of new diagnostic techniques by employing pulsed and continuous-wave lasers and studying the conditions for which instabilities and/or turbulence occur. In addition, the range of arc operation will be extended to higher pressures and power.

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RESEARCH IN STOCKHOLM ON ION IMPLANTATION IN SEMICONDUCTORS*

MAJOR LAWRENCE B. MOLNAR, EOAR

The Crystal Physics Group (CPG) of the Research Institute for Physics in Stockholm, Sweden is engaged in a cooperative basic-research program to investigate ion-implantation processing as a means to achieve the controlled doping of semiconductors. Although ion implantation is a promising technique which offers distinct advantages over diffusion and alloying, many problems must be solved before such processing can be used for device production.

In general, the work of CPG is directed toward realizing a thorough understanding of the implantation process. The Group is therefore assessing the critical factors which influence implants in order to fully characterize ion implantation as a doping technique for semiconductors. The results of this work will be used to compare the implantation process with the more conventional processing techniques.

Particular efforts (as spelled out below) are being directed toward (a) the investigation of ion-range distribution from less than 100 KEV to 2 MEV; (b) location of the dopant in the lattice using Rutherford scattering and nuclear-reaction yields; and (c) disorder due to implantation.

a. Investigations of ion-range distribution include the determination of range-energy relationships, channeling range, substrate-temperature effects, damage effects versus anneal temperature, and misalignment effects.
b. Investigations of the location of dopants include a determination of the influence of channeling on the location, the influence of total dose, the anneal behavior, the roles of solubility and diffusivity, and the interaction of the dopant with interstitials and vacancies created due to irradiation.
c. Investigations of disorders include a determination of the influence of elevated temperature during the implantation, the annealing behavior, the size of individual clusters, and the distribution of damage versus depth.

In addition, other investigations are being performed to determine the transmission of heavy ions through thin single crystals for an insight into the mechanisms of channeling; the degree that channeled distributions can provide deep implantations and more sophisticated impurity profiles; the electrical behavior of implanted samples; and how reproducible implanted profiles can be obtained under conditions that are acceptable for device manufacturing.

In general, CPG's work is oriented toward the exploitation of ion implantation as a means for producing microelectronic devices and circuits. Since ion implantation offers simple masking techniques, low-temperature processing, control of the doping profile and an ability to introduce many and various ion species, this approach

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is recognized as a potentially powerful means to obtain highly reliable, low-power, and small-sized electronic devices and circuits for application in future aerospace systems.

In order to accelerate this progress in ion-implantation technology, the Air Force Avionics Laboratory (AFSC) has encouraged CPG to establish and maintain coordination and information exchange with other research institutions in Europe, Canada and the United States. In this regard CPG has established a formally supported personnel exchange with the Research Chemistry Branch of Atomic Energy of Canada, Limited, at Chalk River, Canada, and the California Institute of Technology in the U.S. Additionally, CPG maintains contact with the University of Aarhus in Denmark, and the Universities of Padova and Catania in Italy.

This exchange of personnel has been viewed by Professor I. Bergstrom, Head of CPG, and by Dr. L. Eriksson, a member of his Staff, as an important aspect of the USAF contractual effort. The various visits and exchanges described below reflect their awareness of this importance.

In June and July of 1968, Dr. J. Mayer of the California Institute of Technology visited Stockholm to participate in several important experimental evaluations of ion-implanted specimens. Shortly after Dr. Mayer's visit, CPG invited the Canadian scientist, Dr. D. A. S. Walker, to Stockholm for six months beginning in October of 1968. Dr. Walker is a research associate at Canada's Chalk River Atomic Facilities where he is a member of Dr. J. A. Davies' ion-implantation research team. While in residence in Stockholm, Dr. Walker was instrumental in designing and constructing special test instrumentation for the ion-implantation isotope separator and a 2-MEV Van de Graaff which is used to investigate implanted specimens.

During Dr. Walker's residency in Stockholm, Prof. Bergstrom arranged a similar exchange for a member of CPG, Dr. N. G. E. Johansson, a physicist. The latter has been in the United States participating in ion-implantation activities at the California Institute of Technology, and working with Dr. Mayer's group on electrical measurements of implanted specimens. This experience is intended to provide CPG with a broad capability to perform experimental investigations of the electrical behavior of implants.

In November 1968, Prof. Bergstrom accepted a request by two Italian scientists to participate in ion-implantation activities at CPG for a period of six months. These scientists were not funded by the USAF. However, support for their residency in Stockholm was obtained from Italian sources, and reflected strong Italian interest in ion-implantation research.

Early in 1969, Dr. Eriksson of CPG visited the University of Aarhus in Denmark. CPG has recognized this University for its outstanding work in atomic-collision and ion-implantation research. Continued coordination with research teams at Aarhus has been considered essential, and Dr. Eriksson intends to visit Aarhus again. In addition, he has planned visits to the University of Oslo, where a research team is apparently developing a capability to perform implantation research.

The Canadian scientist, Dr. Davies, has planned to take a leave of absence from the Chalk River Facilities and spend one year at the University of Aarhus. During his stay in Denmark, Prof. Bergstrom intends to invite Dr. Davies to Stockholm for several short visits.

The author has learned that Prof. Carter at the University of Salford, U.K., is forming an atomic-collision and ion-implantation group, and has encouraged Prof. Bergstrom to consider cooperation with this group.

From the above, it is quite evident that CPG has established definite goals, and has sought to closely coordinate its experimental work with the activities of other groups working in the same areas. It is anticipated that this continued cooperative effort will result in rapid advances in ion-implantation technology.

The research of CPG itself has been described in a number of articles which have appeared in such prominent journals as *Science, Applied Physics Letters, Nuclear Instruments and Methods, Radiation Effects, Journal of Electrochemical Society,* and others.

DR. JOSE C. MANTHURUTHIL
General Physics Research Laboratory, ARL

elastic proton scattering

The study of nuclear systems has two aims: (1) by assuming some properties of the nuclear force, one tries to understand the structure of nuclei in their stable or metastable states, and the way in which the interactions between such structures proceed; (2) by observing properties of nuclei and nuclear reactions, one hopes to infer enough information about the nuclear force to reach the origin of the force—namely, the meson fields which transmit it from nucleon to nucleon. Not much can be said about the second approach since we know very little about the strong interactions at the present time. Because so little is known about the nuclear force, we are required to represent it by potentials, usually limited to interactions between pairs of nucleons for simplicity. Using these potentials, one can construct theories which, by comparison with experiments, may lead to either a unique determination of the potential or at least to a restriction of the possible types of potentials.

Even with the assumption of simple potentials, determination of the exact solutions for the resulting nuclear structures is very difficult when there are more than two nucleons. Obviously we have to introduce simplifications, and this is done by the use of a "model." A model is, therefore, a type of structure corresponding to interactions that are simple and solvable. One can improve the predictions of the model by studying the effect of residual interactions which are defined as the difference between the actual force and those prescribed in the model. The idea, then, is to find a model which imitates the actual structure sufficiently to make the effects of residual interactions small. In nuclear physics, the "Shell Model" to a degree satisfies the above requirements.

It is the purpose of this article to indicate that elastic scattering can be a powerful tool for the study of nuclear potentials themselves and, also, to test the "models" which are usually used for complex structures, that is, those involving more than two nucleons. Figure 1 is a graphic representation of the nuclear potential and the possible processes that can occur in elastic proton scattering. Incoming protons first encounter the repulsive Coulomb potential, and then the attractive nuclear potential represented as the deep well. The dotted lines represent the quasibound states of the system. The following three processes may occur:

(a) The proton is scattered from the Coulomb potential and gives rise to the well-known Rutherford or Coulomb scattering.

(b) The proton penetrates the Coulomb barrier and comes under the influence of the nuclear potential. The scattering is small at low proton energies, but increases very rapidly with energy.

(c) When the proton's energy comes close to the energy of one of the quasibound levels of the system, the proton can be captured and re-emitted after a short time. The differential cross section for elastic scattering becomes very large at this proton energy, and we then have resonance scattering.

We shall now discuss each case individually.

The differential cross section for the scrattering of a

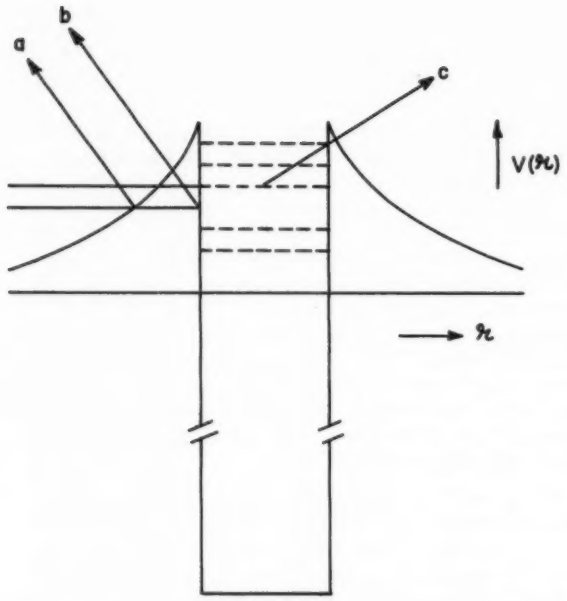

Figure 1. A graphic representation of the nuclear potential and the possible processes that can occur in elastic proton scattering. The dotted lines represent the quasibound states of the system.

charged particle from a point charge can be described by the following formula, due to Rutherford:

$$\frac{d\sigma}{d\Omega} = CE_p^{-2}\,\mathrm{Sin}^{-4}\,(\theta/2).$$

C is a normalization constant, E_p is the proton energy, and θ is the angle at which the protons are detected. This process is well understood and, therefore, will not be discussed in detail here.

The second process, nuclear scattering, gives us important information about the nuclear potential and, consequently, about nuclear force. We shall restrict the discussion to two nucleon systems. Analysis of elastic scattering data has led to important conclusions about the nuclear force. One such conclusion is that the nuclear force is "charge-independent"–that is, the neutron-neutron, neutron-proton, and proton-proton interactions are all equal, aside from the Coulomb effect. Availability of experimental data has led theorists to propose specific forms of the two-body nuclear potential to explain the data. Examples of these are the Hamada-Johnston, (1) Yale, (2) and Tabakin (3) potentials. Even though these potentials explain the two-nucleon data, in general, they are not the potentials used in the calculations of complex nuclear systems. This is an important problem and meets with considerable difficulties when one tries to solve it. This is partly due to the fact that the extensive data available on the two-nucleon interaction does not determine the potential uniquely because the data is limited in accuracy and range and is troubled by inherent ambiguities. Furthermore, the two-nucleon data gives no information about the three-nucleon or many-nucleon forces that might be present in appreciable strength. All present work is carried out on the assumption that only two-body forces act, because it would be difficult to do otherwise. A failure to fit the data on complex nuclei in terms of two-nucleon interactions consistent with the two-nucleon data would be evidence of many-body interactions. Recently, Kuo and Brown (4) and others have tried, with some success, to fit data from complex nuclei potentials derived from two-body data. What is obviously needed is further experiments and theoretical calculations.

The third process, resonance scattering, can yield considerable information about the structure of complex systems and thereby test nuclear models. We will limit the discussion to elastic scattering at low energies where process (b) can be neglected. The amplitude for elastic proton scattering at an isolated resonance will then contain only two terms: f_c for Rutherford or Coulomb scattering, and f_r for resonance scattering; f_r is non-zero only when the proton energy is close to the resonance energy. The differential cross section can be written as:

$$\frac{d\sigma}{d\Omega} = \left|f_c\right|^2 + \left|f_r\right|^2 + 2\,\mathrm{Real\ Part}\,(f_c^{*} \cdot f_r)$$

where f_c^{*} is the complex conjugate of f_c. The interference term introduces a change in the normally symmetric pattern of the resonance scattering, and the extent of this change conveys information about the orbital angular momentum of the captured proton. Thus, by measuring the cross section, one can obtain the ℓ-value of the proton. One can also deduce the total angular momentum $\vec{J} = \vec{\ell} + \vec{s}$ of the resonance from experiments that distinguish the two possible spin states of the outgoing proton's intrinsic spin s. If the number of outgoing protons with spin parallel to a specified direction is N^{+}, and the number with spin antiparallel is N^{-} then the polarization is given by

$$P_R = \frac{N^{+} - N^{-}}{N^{+} + N^{-}}$$

The quantity P_R can be obtained by rescattering the elastically scattered protons from a second target, usually carbon, and measuring the number of protons moving through the same angle in the scattering plane to the right and to the left of the beam axis. The behavior of the proton polarization P_R at the resonance is distinctive and unambiguous; if the polarization peaks at resonance for $J = \ell + 1/2$, it dips for $J = \ell - 1/2$.

Extraction of the "spectroscopic factor," essentially the fraction of a state that has the configuration of a single particle plus inert core, is also indirectly possible from elastic-scattering data. In the case of elastic scattering, this is contained in the "reduced width." Reduced widths can be obtained by first extracting the natural proton width Γ_p from experimental data. The proton width Γ_p is proportional to $P\gamma_p^2$, where γ_p^2 is the reduced width (essentially the rate at which the compound nucleus forms a state with a single proton having its elastic energy), and P is just the probability that this proton can escape by

penetrating the Coulomb and centrifugal barriers surrounding the nucleus. The reduced width is related to spectroscopic factor S by the simple relation

$$\gamma_p^2 \approx \frac{S}{2T_o + 1}\ \gamma_{sp}^2$$

where γ_{sp}^2 is the expected width for a true single particle state, and T_o is the isobaric spin of the target nucleus.

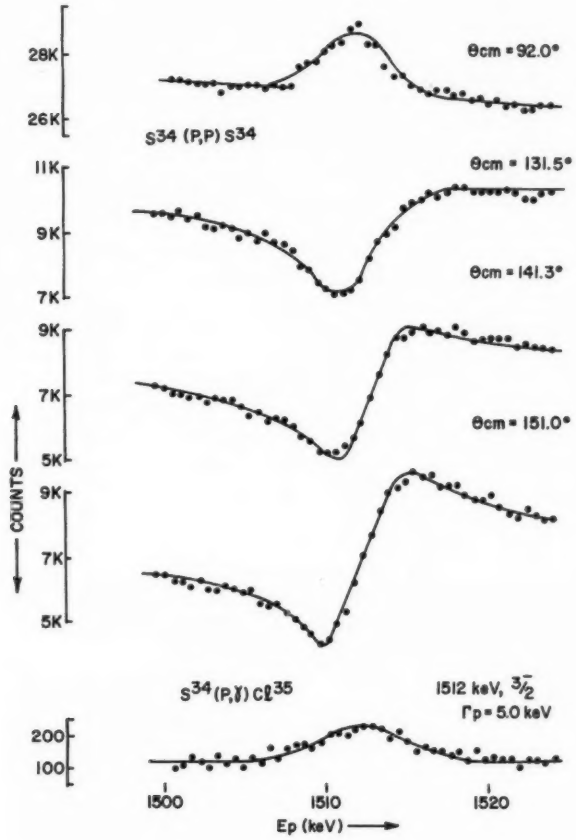

Figure 2. S^{34} (p, p) S^{34} elastic-scattering data taken at 4 different angles. The final curve is the yield of the S^{34} (p, γ)Cl^{35} reaction.

Elastic-scattering resonances at low energies usually have narrow widths in energy and therefore, to observe them, one has to use particle accelerators that have high-energy resolution. The Aerospace Research Laboratories' ICT Tandem Accelerator described by Anderson (5) has the high-resolution capabilities needed to study elastic-scattering resonances. Figure 2 shows the proton elastic-scrattering data obtained by bombarding an enriched sulphur-34 target with a proton beam of about 1510-keV. Analysis of these data yielded an ℓ-value of 1 and a natural width of about 5-keV for the resonance. The data shown in Figure 3 was not chosen as a typical example of the high-resolution capabilities of the machine, but instead was chosen as an example of the important class of states called "isobaric analog states." However, resonances having natural widths of a few electron volts have been observed in the Laboratory.

In order to identify the isobaric analog states, it is essential to know the ℓ-value and natural width of the resonances. For a detailed discussion of isobaric spin and isobaric analog states, the reader is referred to the recent articles by Coker and Moore (6) and by Harris. (7) It is sufficient to say here that elastic scattering is a powerful tool for identifying and studying isobaric analog states, and that such studies can provide considerable information about nuclear structure. As previously stated, Figure 3 shows the data obtained at an isobaric analog state in Cl^{35} This state at 7.84-MeV in Cl^{35} is the analog of a state in S^{35} at 2.35-MeV, and has the simple configuration of an inert core plus a particle, the particle being in the $p_{3/2}$ orbit. Another analog state at 7.54-MeV in Cl^{35} (the analog of a state in S^{35} at 1.99-MeV) has been found, and it also has the simpler configuration of an inert core plus a particle; but in this case the particle is in the $f_{7/2}$ orbit. Analog states with such simple configurations have also been found in other nuclei such as P^{31} and Cl^{37}

Finally, elastic scattering can be used to study the properties of bound states. An example of this is shown in Figure 3. The figure shows the decay of the Cl^{35} resonance

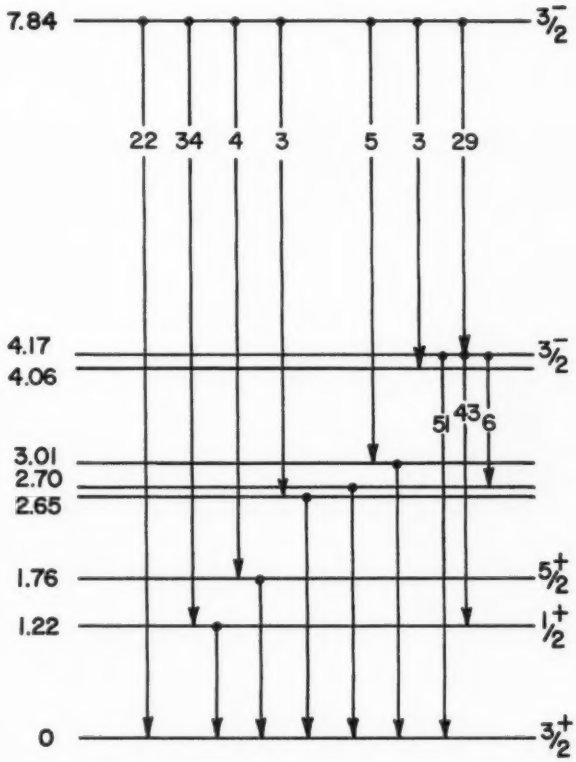

Figure 3. The γ-ray decay scheme of the 7.84-MeV resonance state. The numbers following each transition are the branching ratios.

state at 7.84-MeV to bound states by γ-ray emission. A simple elastic scattering (without the measurement of polarization) yields the ℓ-value of the resonance state. In this particular case the ℓ-value is 1, so that the resonance state can only have spin 3/2 (corresponding to $\ell + 1/2$), or spin 1/2 (corresponding to $\ell - 1/2$). Angular distribution or correlation measurements of the transitions to bound states with known spin can, in most cases, uniquely determine the spin of the resonance state. A knowledge of the resonance spin (in this case 3/2) can be used in the analysis of correlations involving bound levels with unknown spin yielding the spin of these bound levels. An application of such a procedure yielded the spin of the 4.17-MeV level, shown in Figure 3 to be 3/2. A knowledge of bound-state spins and electormagnetic decay properties provides a good test for the models introduced at the beginning of this article.

Dr. Jose C. Manthuruthil joined the Nuclear Structure Group, General Physics Research Laboratory, ARL as a research physicist in 1964. Born in Kaipuzha, India, he attended St. Thomas College at Palai, and Peona University at Peona, both in India. At the latter, he earned his B.S. in Physics and Mathematics in 1956. He subsequently received his M.S. in Physics from the University of Detroit in 1960 and, in 1964, his Ph.D. in Physics from Indiana University.

At present, Dr. Manthuruthil is engaged in the investigation of the properties of nuclei in the $28 \leq A \leq 50$ region. He is using the techniques of low-energy proton-capture reactions and gamma-ray spectroscopy to determine the spins, parities, and energies of nuclear excited states in the above region. He is a member of the American Physical Society, and has a number of publications to his credit.

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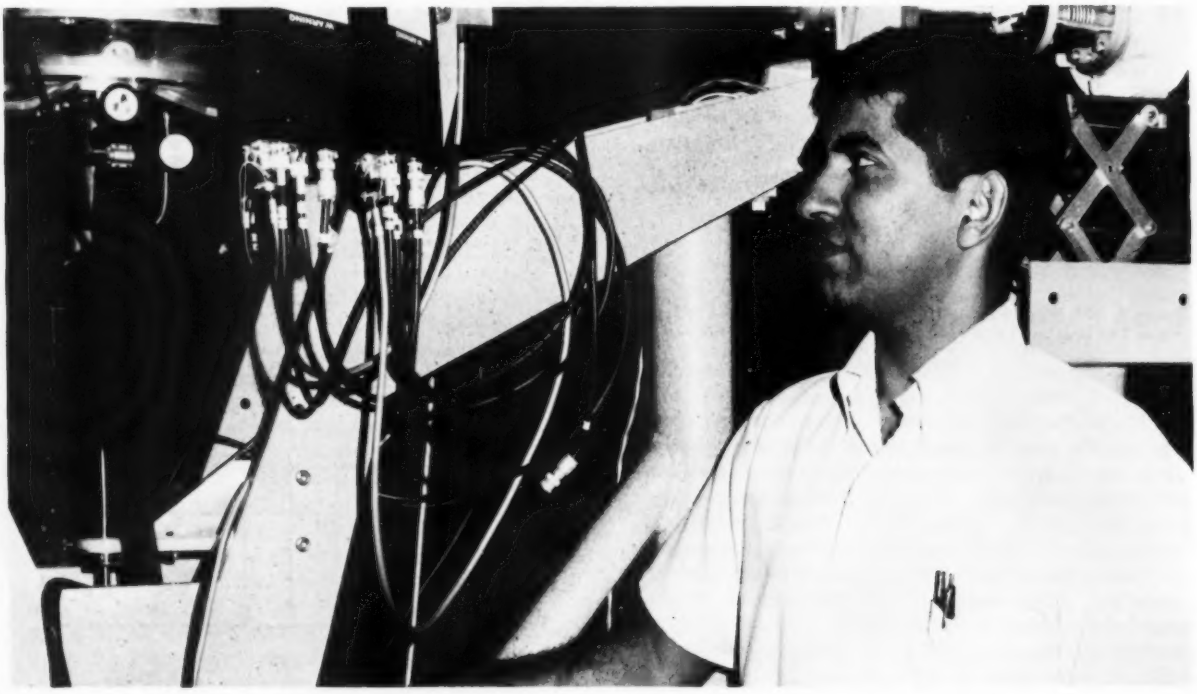

Dr. Manthuruthil watching the scattering chamber.

additives - a search for understanding

ROBERT L. TISCHER
Chemistry Research Laboratory, ARL

A subject of considerable practical as well as theoretical interest is the effect of additives on combustion phenomena. There is a continuing need for chemicals which can act as fire retardants, suppress or enhance ignition characteristics and, in general, afford some control over flammability limits, propagation rates, and other combustion parameters. The more preferable additives are those which produce the required effect when present in only small quantities. The suppression of knock by small concentrations of lead tetraethyl is a prime example of an effective additive. It thus becomes desirable to learn in just what way those additives which are effective achieve their results.

The inhibitory effects of halogen-containing compounds on the propagation rate of hydrocarbon-air flames have been known for some time; but the mechanisms by which they exert these effects are not fully understood. One hypothesis is that these compounds, react with hydrogen atoms, thereby reducing the concentration of this highly reactive and important flame intermediary. In order to test this concept, Corbeels and Scheller,(1) and, more recently, Tischer and Scheller (2) have investigated the effect of halogen-containing additives on hydrogen-halogen flames.

For practical reasons the hydrogen-chlorine system was selected. Chlorine gas is handled easily and presents none of the difficult experimental problems associated with bromine. Fluorine, on the other hand, is so highly reactive as to be undesirable for such a study. An advantage shared by all hydrogen-halogen reaction systems is the small number of species which exist during the course of reaction. In the case of hydrogen-chlorine there are only five (H, H_2, Cl, Cl_2, and HCl); this increases to six when nitrogen is used as a diluent, as was the case in this work. A disadvantage is that experimentation must be conducted in a darkened room to preclude the action of light on chlorine.

The flames of hydrogen and chlorine were found to have a rather limited range of stability, manifested by such distortions of the usual flame cone as opentips, curved and even dome-shaped cones, and cellularity. All of these distortions become more pronounced as the amount of nitrogen dilution is reduced. This behavior is attributable to the large differences in molecular weight of the reactants, a fact that gives rise to strong diffusional effects.

Experimental values for burning velocities are shown in Figure 1. Regular geometrical cones, suitable for reliable measurement, were obtained only for medium-rich mixtures (R = 0.60 and R = 0.65). Experiments with additives were confined to flames with

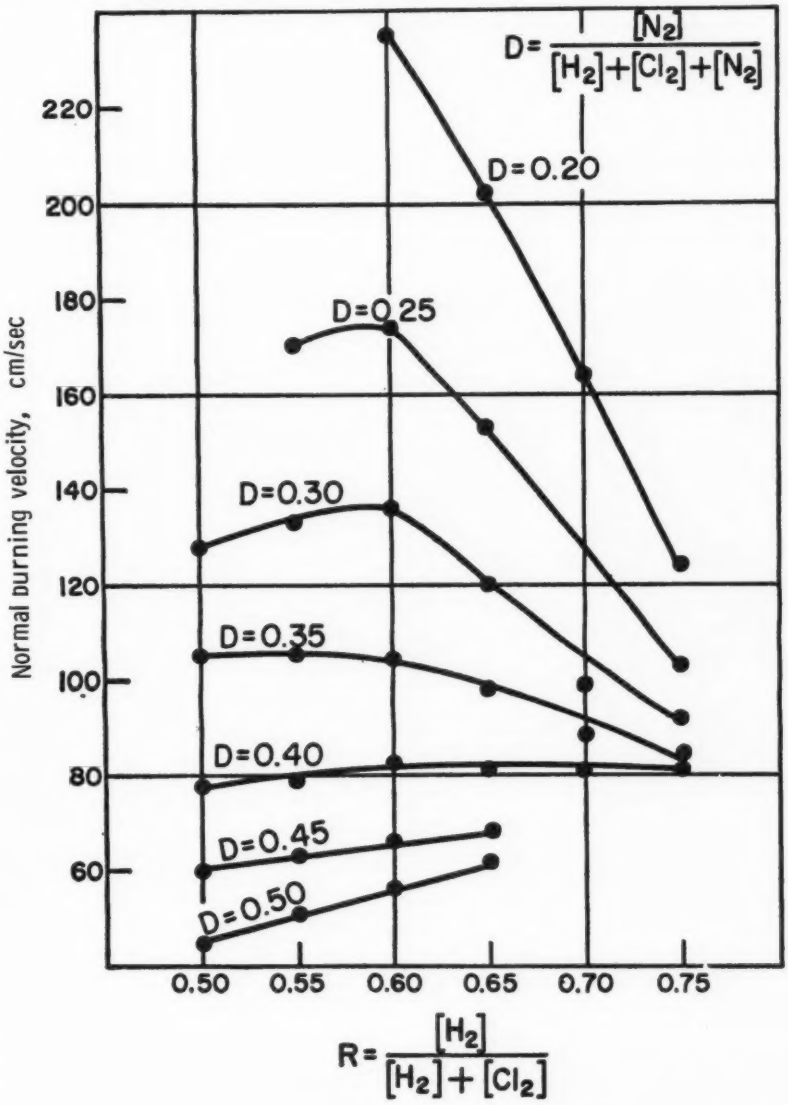

Figure 1. Experimental burning velocities of hydrogen-chlorine-nitrogen mixtures at atmospheric pressure. [Data from Corbeels and Scheller. (1)]

a mixture ratio R = 0.60, and D = 0.30, since this mixture gives a maximum burning velocity (for this particular diluent) and yields the most suitable flame for measurement.

Contrary to expectations, most of the chlorine-containing additives produced an increase in propagation rate. Examples are shown in Figure 2. Additional compounds tested include chlorinated derivatives of methane and carbon tetrafluoride, chlorides of Group Va elements, and boron trichloride, which is inert. Among other conclusions, the results indicate that dissociation reactions of the additive molecules appear to be responsible for their behavior in this system.

An interesting, and perhaps important, additional bit of information uncovered during the studies concerns the effect of air entrainment. It was found that the complete elimination of air from the surrounding atmosphere causes the flame to lose its characteristic greenish-yellow color and become totally invisible. The additive-free flame also becomes unstable, suffering blowoff. The propagation velocity, however, does not appear to be affected.

While the results of this effort have not provided an answer to the original question, they do show the need for more information on the dissociation characteristics of additives, and point the way for future studies.

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Mr. Robert L. Tischer has been a research chemist at the Chemistry Research Laboratory, ARL since 1959 where he is presently engaged in studying the radiative behavior of selected flame systems. He is also continuing his investigation of flame propagation in gases, the mechanisms and kinetics of combustion reactions, high-temperature gas kinetics, and the kinetics of detonation waves.

Mr. Tischer earned a B.S. in Chemical Engineering from the University of Dayton in 1956, and an M.S. in Chemical Engineering from Iowa State College in 1959. While studying for his graduate degree, he was a research assistant at AEC's Ames Laboratory.

Mr. Tischer is the co-author of several publications, and has presented the results of his studies at several scientific meetings. He is a member of the American Institute of Chemical Engineers.

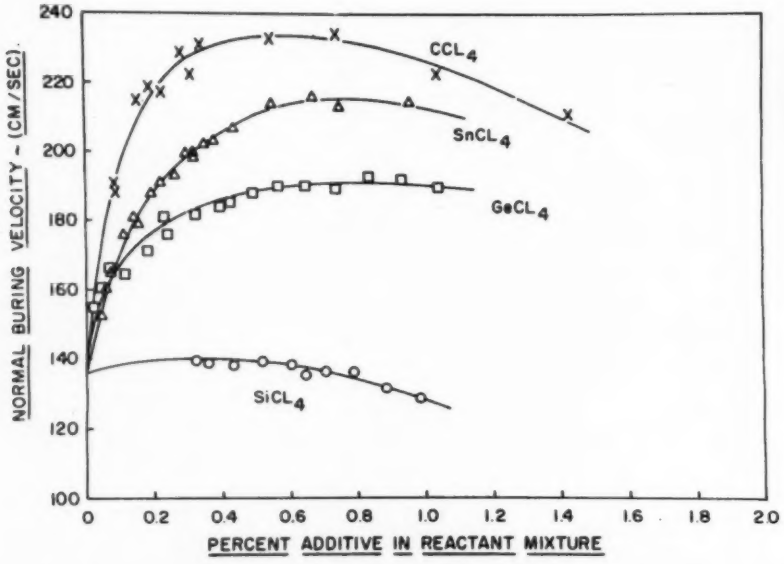

Figure 2. Effect of additives on the burning velocity of a 42/28/30 hydrogen-chlorine-nitrogen mixture at atmospheric pressure (Group IVa chlorides).

EMISSION FROM EXCITED TERMINAL STATES OF BOUND EXCITON COMPLEXES

DONALD C. REYNOLDS, Director, Solid State Physics Research Laboratory, ARL

Measurements of magnetic-field splittings of donor and acceptor impurities in semiconductors allows one to study the ionization energies of these impurities, as well as the effective masses of the carriers. Studies of this type have been made on a number of different impurities in Si and Ge. (1), (2), (3) These investigations were made by studying infrared absorption in a magnetic field.

The highest-quality crystals obtainable in II-VI materials are platelet-type crystals. These crystals are very thin (0.5μ - 50μ); as a result, they are not suitable for infrared absorption studies. A detailed description of the bound exciton complexes in one of these materials (CdS) has been presented by Thomas and Hopfield. (4) They point out that an exciton bound to a neutral donor (or acceptor), upon decaying, could leave the donor (or acceptor) in an excited state. Investigations of this type offer another approach to the study of donor or acceptor impurities in a particular host lattice.

It is the purpose of this paper to report on bound exciton transitions in CdS in which the impurity is left in an excited state. The transitions have been associated with donor-type complexes in which the initial state is that of an exciton bound to a neutral donor, and the final state is that of an excited state of the electron on the donor.

In dealing with this type of complex in a material having the wurtzite symmetry, it is possible to examine directly the magnetic-field splitting of the electron on the donor. It was previously shown (4) that, for the wurtzite symmetry, the electron g-value is isotropic, (g_e = isotropic). It was further shown that the hole g-value is completely anisotropic ($g_h = g_{h\parallel}\cos\theta$), where θ is the angle between the "c" axis of the crystal and the magnetic-field direction. If one does an emission experiment in the orientation C⊥H then, in the upper state (see Figure 2), the electron spins are paired to give a bonding state and one is left with a degenerate hole spin. For this orientation the hole g-value is zero, so there will be no magnetic-field effect on this state. In the lower state, since the electron g-value is isotropic, the electron will split according to the state it occupies. In the ground state one will observe the usual electron-spin splittings. In an excited state, one will observe orbital splitting as well. In this configuration, one is observing transitions from a singlet upper state to a magnetically split lower state. This provides a direct observation of the ground and excited states of the electron on the donor.

From zero-field measurements, we have been able to determine donor binding energies, and magnetic-field measurements have permitted the determination of the electron effective mass. Measurements in other orientations ($0° \leqslant \theta \leqslant 90°$) have demonstrated the additional multiplicity due to hole splitting.

In the present experiment, five lines are observed in zero field at 2.5214 eV, 2.5220 eV, 2.5235 eV, 2.5254 eV, and 2.5262 ev. The magnetic-field splitting of these lines identified them as excited states of bound exciton complexes.

In order to relate the energy states of a particular series, it is necessary to calculate the "hydrogen-like" ground and excited states of a neutral donor. The method

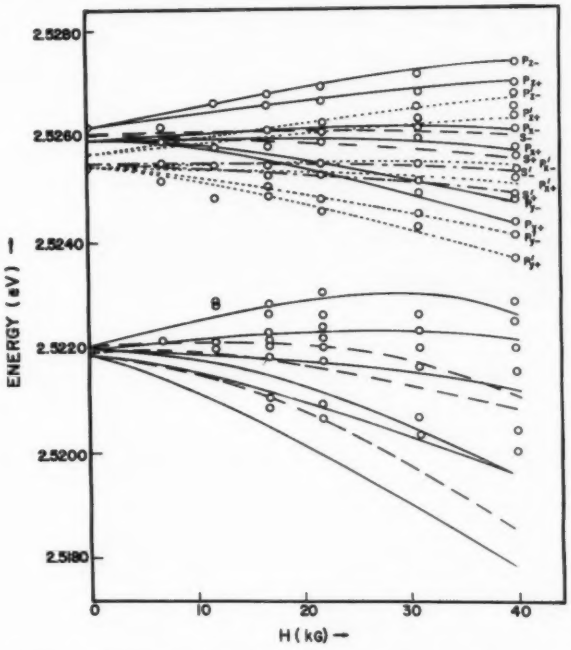

Figure 1. Photon energy of the n=2 and n=3 states of the I_{2c} and I_5 neutral donor bound exciton complexes as a function of magnetic field for the orientation C⊥H.

chosen is analogous to the one used by Wheeler and Dimmock (5) where they derived the energies of an exciton in an anisotropic crystal. The effective mass of the electron in the neutral donor "hydrogenic" model is assumed to be isotropic; however, the dielectric constant in the z direction is different from that in the x and y directions. As a result, one must account for the dielectric anisotropy. Terms are also included for the linear Zeeman effect, the quadratic Zeeman effect, and the interaction of the spin momentum with the magnetic field.

The resulting energies obtained from the calculation, for the n=2 and n=3 states of the donor complexes, as a function of the magnitude of the magnetic field, are given as solid and dashed lines in Figure 1. It is apparent that there are two overlapping sets of n=2 states derived from separate donors. The calculated energy of the n=2 state of the donor was matched to the experimentally observed n=2 state. From the calculated binding energy of the donor (0.026 eV), one can calculate the ground-state donor

energy. Applying this binding energy to the solid and dashed lines of Figure 1 gives a good fit to the I_5 and I_{2c} (4870.2A) levels respectively. (6)

In the calculated energy levels of Figure 1, an electron effective mass $m_e^* = 0.18\ m_o$ was used. This gives a good theoretical fit to the experimental data.

The calculated energies for the n=3 states are shown in Figure 1. In this calculation, the spin was not added for the sake of clarity; likewise, only the n=3 states of the I_5 donor are included. The fit between theory and experiment is not as good for the n=3 states as it is for the n=2 states. This probably results from the large radius of the donor causing mixing of states of a different principal quantum number, through the diamagnetic term, for larger quantum numbers. It is apparent, however, that the experimental energies of the n=3 states do come in the region where one calculates them to be, and that they do fit the hydrogenic series for the calculated donor binding energies.

The model used to describe the magnetic-field splittings is shown in Figure 2. It is evident from the model that

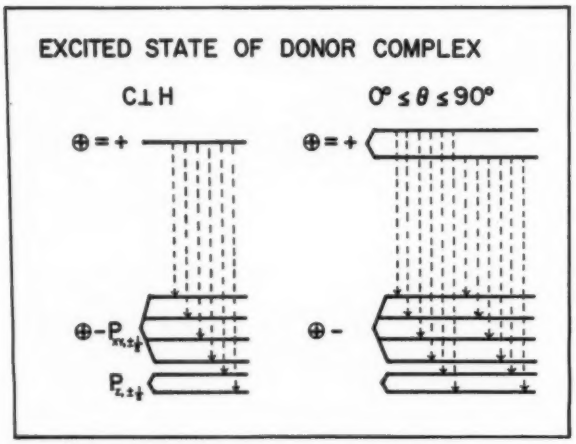

Figure 2. Model for the decay of a bound donor complex in which the decay of the exciton leaves the terminal state in an excited configuration, in this case a p-state.

the lowest energy transitions result from the highest excited states. The model also demonstrates how the calculated positive diamagnetic shift is translated into a negative diamagnetic shift. Negative diamagnetic shifts are observed for the transitions in Figure 1. It can further be seen from Figure 2 that, as the "c" axis of the crystal is rotated with respect to the magnetic-field direction, a contribution from the hole spin should be observed. Figure 3 shows the splitting of the zero-field lines at 2.5214 eV and at 2.5220 eV as θ is varied from 0° - 90° for a constant magnetic field of 40 KG. For the orientation C ∥ H, only three lines are observed for these excited states. In the magnetically split lines (Figure 3), the outer pair of lines (high and low energy) split as the sum of the g-values ($g_e + g_h$), and the inner pair of lines split as the difference of the g-values ($g_e - g_h$). If the electron and hole g-values are nearly equal, the inner pair of lines will show no splitting, and the outer pair of lines is not allowed by spin consideration. This explains the splitting for the C ∥ H orientation in Figure 3. It was previously shown (7) that the electron and hole g-values for the I_2 and

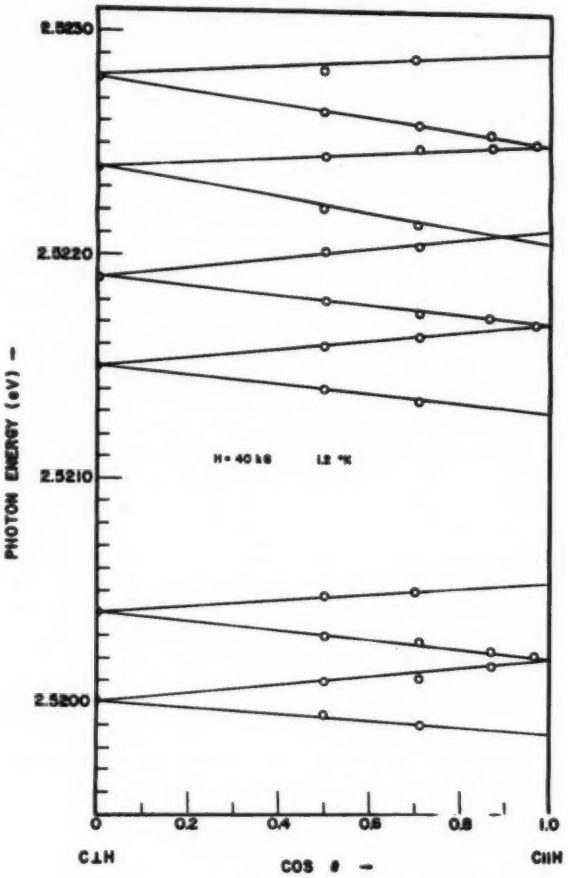

Figure 3. Magnetic-field splitting of the zero-field 2.5220 eV line as a function of cos θ for a constant field of H = 40 KG.

I_5 complexes in the ground state were approximately equal.

The study of the terminal states, after the decay of bound exciton complexes, is a technique for gaining information about impurity states in semiconductors. It has been shown that, after exciton decay, the donor electron is left in an excited state in a number of transitions. From the differences in energies of the transitions to various excited states, one can determine the donor binding energies. Studying the same excited states in a magnetic field has yielded carrier effective mass information.

In the case of CdS, only excited terminal states were observed for donor complexes. There is no *a priori* reason why similar effects should not be observed for acceptor complexes. The technique should be applicable to any material where well-resolved bound exciton lines are observed.

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Mr. Donald C. Reynolds joined the Physics Research Branch, ARL, as a research physicist in 1952. In 1956, he was advanced to supervisory research physicist of the Branch and, in 1964, became Chief of the Solid State Physics Research Laboratory. At present, he is the Director of this same Laboratory.

Mr. Reynolds received his B.S. in Physics from Morningside College, Sioux City, Iowa in 1943, and his M.S. in Physics from the University of Iowa in 1948. He also attended the Communications School while serving as a lieutenant in the U.S. Army Air Corps.

Currently, Mr. Reynolds is engaged in the investigation of CdS- and ZnS-type semiconductors, particularly the nature of the electronic phenomena of synthetic CdS, ZnS and mixed Zn, CdS crystals. He has a number of patents to his name, and over 100 Scientific publications to his credit. He received the ARDC award for Meritorious Civilian Service in 1957, and was a nominee for the DOD Distinguished Civilian Service Award in 1962, for which he was awarded $5,000 in cash.

DO OPTICAL PHOTONS INTERFERE ONLY WITH THEMSELVES ?*

DR. LEONARD MANDEL, The University of Rochester

The formation of interference fringes of light was thought to be well understood ever since the early 19th century. At that time the pioneering work of Young and Fresnel had appeared to settle once and for all the much-debated question of whether light should be regarded as a propagating wave or as a stream of particles. Their work settled the question decisively in favor of the former, arguing that interference fringes were the visible evidence of the alternate reinforcement and cancellation that occurs when two light waves are superposed in space (see Figure 1). This explanation was accepted until modern times.

The introduction of the quantum theory of radiation in the late 1920's, coupled with the experimental evidence that light appeared to be emitted and absorbed in the form of discrete packets of energy or quanta (photons), again cast doubt on the wave theory. At sufficiently low light intensities, the interference fringes could be resolved into discrete random light flashes which appeared most frequently at the maxima of the fringe systems and least frequently at the minima.

Certain paradoxes were much discussed at this time. If light really consists of discrete photons traveling in straight lines, and if these photons pass through either aperture A or B in Figure 1 on their way to the receiving plane where interference fringes are formed, how are we to explain the

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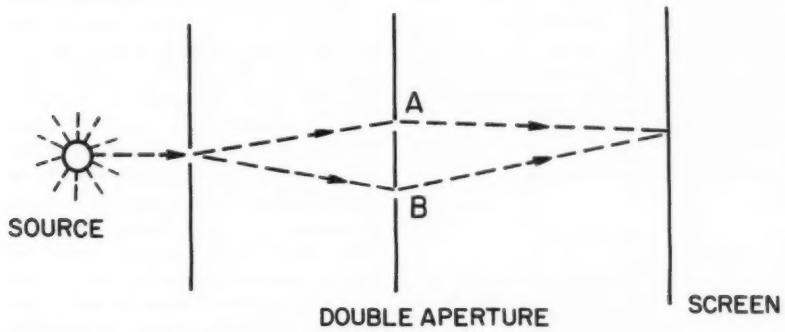

Figure 1. Principle of Young's double-slit interference experiment.

experimental fact that *both* apertures must be open for interference fringes to be formed? The answer provided by the quantum theory struck profoundly at the classical view of the natural world. Since the photon cannot, in principle, be detected as passing through one or the other aperture without destroying the interference pattern, the question is without physical content. The photon should not therefore be considered as passing through *either* aperture A or aperture B, but rather as passing through *both* apertures at once; thus it is the probability amplitudes for the two trajectories of each photon which interfere. Therefore, there is a curious sense in which the source may be regarded as emitting photons simultaneously into both beams, and 'each photon interferes only with itself' to produce the observed fringe pattern.(1)

A recent experiment on the interference of light from two separate lasers has resuscitated this paradox in a more acute form.(2, 3) It was demonstrated some years ago that interference fringes can be observed when light beams from two quite independent lasers are superposed (see Figure 2), provided the observation time is kept sufficiently short. The question then arose as to whether these experiments give evidence of the interference of one photon from one source with one photon from the other source. On the face of it they appear to do so; although it is possible for a photon from the source to enter both beams in the arrangement of Figure 1, this appears to be impossible in Figure 2. On the other hand, if photons from one source interfere with those from the other, this would appear to require coincident arrival at the detector. If the light intensity were reduced until the average interval between photons was great compared with their transit time through the apparatus, so that one photon was absorbed at the detector before the next one was emitted at the source, the interference fringes could be expected to disappear. However, a recent experiment in which these conditions were satisfied (2, 3) showed that the interference fringes persisted. This observation suggests that the phenomenon is not describable in terms of the interference of one photon from one source with another photon from the other source.

The light beams, obtained from two independent He:Ne lasers (see Figure 3), were attenuated until the average interval between photons was about 1/5 μsec. If a photon is absorbed at the instant at which the photoelectric pulse appears, and if it travels with velocity c from the source to the detector, its total lifetime within the interferometer is only two or three nsec. Therefore, the probability of two photons overlapping within the apparatus was only about one percent.

Since the phases of the two lasers were not locked together, all observations of interference fringes had to be made in a very short time (about 20 μsec) to ensure that no significant drifts occurred. Because of the low quantum efficiencies of optical detectors, only a few photons were actually registered in each trial, and the interference fringes were identified indirectly by a statistical technique. As can be seen from Figure 3, the interference detector consisted of a stack of transparent plates arranged so that light falling on adjacent plates was directed to two different photomultiplier tubes, which counted the photons. It can be shown that if interference fringes are present, with a half-fringe spacing corresponding to a plate thickness, then the numbers of counts registered by the two phototubes in repeated trials should have a negative correlation. However, if no fringes are present, so that each photon has a nearly uniform probability of appearing anywhere on the receiving plane, there should be zero correlation. In this way it was possible to show conclusively that interference occurs even under conditions in which the light intensity is low enough for one photon to be absorbed before the next one is emitted.

How is this result to be interpreted? To describe the phenomenon in terms of photons, we must conclude that it cannot be attributed to the interference of one photon with another; rather it seems that even here each photon interferes with itself to produce the fringe pattern. But in this instance, the paradox is even more acute. Whereas, in the arrangement of Figure 1, each emitted photon has a certain non-zero probability amplitude of being found in each beam, it would seem that in Figure 2 a photon emitted by one source would have a zero probability of being found in the other beam, so that no interference ought to take place.

The quantum mechanical explanation once again forces us to adopt a viewpoint which is remote from intuitive, everyday experience. A detailed argument can show that the mere observation of the interference fringes makes it impossible, in principle, to determine from which source each photon came. We cannot, therefore, associate each photon with *one or the other* source, but have to regard it as seeming to come from *both* sources (even though the sources cannot emit photons into both beams at once). This paradoxical situation arises because the detection of the photon forces it into a state in which the possible trajectories are intrinsically indistinguishable. Indeed, the phenom-

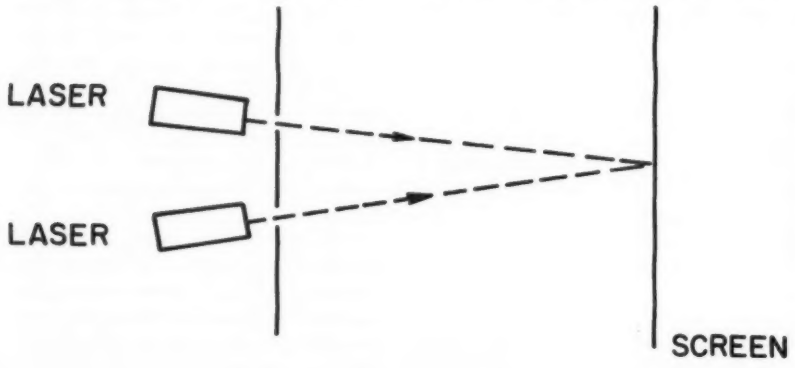

Figure 2. An interference experiment with light beams from two independent lasers.

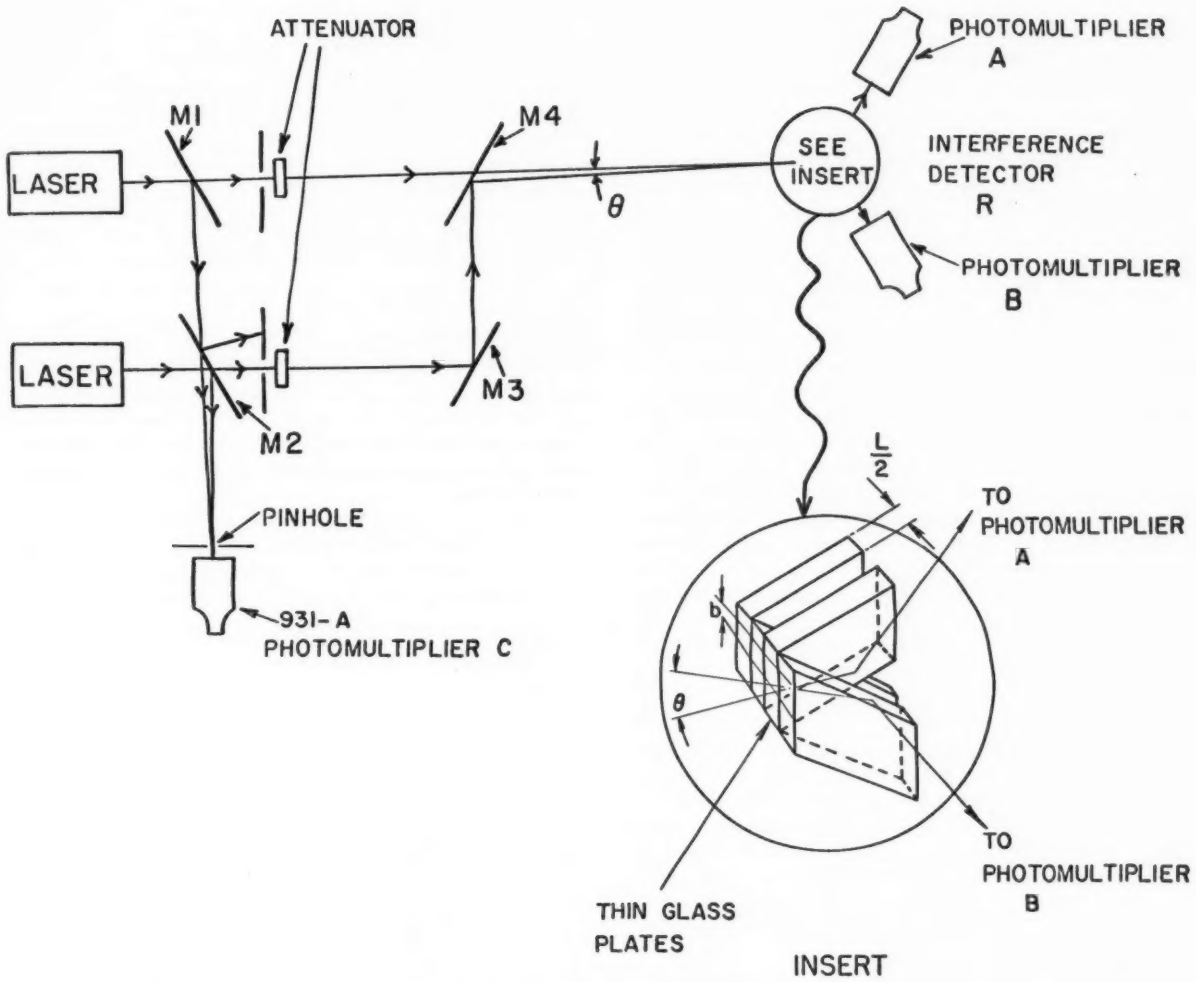

Figure 3. Outline of the apparatus used to observe interference fringes with beams from two sources, under conditions in which one photon has a high probability of being absorbed before the next one is emitted (see Refs. 2 and 3).

enon is an example of what seems to be a rather general physical principle—that interference effects are manifestations of fundamentally indistinguishable events.

Although everyday concepts are not entirely suitable for the understanding of quantum mechanical effects, this is, roughly speaking, the point of view we are forced to adopt if we wish to describe the phenomenon in terms of photons. It is a point of view which is intuitively unattractive to many people, and it is therefore tempting to discard the photon concept altogether and to deal only with light waves in discussing these experiments. However, while the purely classical treatment avoids the foregoing paradox, it leads to other difficulties. For example, it cannot account for the virtual impossibility of performing such interference experiments with light from ordinary sources. Other descriptions, which are intermediate between the classical and purely quantum mechanical points of view, have also been attempted;(4) but we have to face the fact that an entirely satisfying explanation has not yet been given.

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After obtaining his Ph.D. in Nuclear Physics from the University of London in 1951, Dr. Mandel held positions in industry and at Imperial College in London. He is a Fellow of both the American Physical Society and the Optical Society of America.

chemical modification of ignition temperatures

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It is an interesting and significant fact that small quantities of a variety of substances can exert a profound effect on the combustion of hydrocarbon fuels with air. Most additives serve to inhibit the combustion process, while a relatively few materials, organic nitrates, peroxides or ethers, which must be present to the extent of 5% or more by volume in liquid fuel for effective action, are known to be promoters. In view of this circumstance, it is not surprising that the bulk of the published literature in this field is devoted to the effect of inhibitors on the burning rate.

Extensive data have been reported on the effect of compounds such as $Pb(C_2H_5)_4$, $Fe(CO)_5$, the methyl halides (CH_3I, CH_3Br, CH_3Cl), and the Group-IVa chlorides ($SnCl_4$, $GeCl_4$, $SiCl_4$, CCl_4) on the burning velocity of premixed laminar hydrocarbon flames and the flammability limits of diffusion flames. Little information is available on the effect of additives on other characteristics of the combustion process. Recently, Morrison and Scheller (1) have reported on the effects of a large number of burning velocity inhibitors on the ignition temperature of propane-air mixtures. A thorough understanding of the role played by such compounds on the ignition process might lead to better techniques for fire suppression and possibly combustion promotion. Additives, which decrease the ignition temperature, may be of considerable value in increasing the effectiveness of supersonic combustion systems now under development.

The hot-wire ignition temperature of propane, air, and additive mixtures was measured as a function of stoichiometry, oxygen content, and additive concentration. The test gases were metered into a 35-mm quartz tube. An electrically heated nickel-chromium wire, which had a diameter of 0.86 mm, traversed the diameter of the tube. The temperature of the wire was measured with a pyrometer and reported as the black-body temperature at 6500Å. Ignition was defined as that point where a visible flame or flashback was observed.

The first studies were carried out with the Group-IVa chlorides. These data are shown in Figure 1 for the ignition of a stoichiometric mixture of propane and air (21% O_2). All four compounds have been previously reported as burning

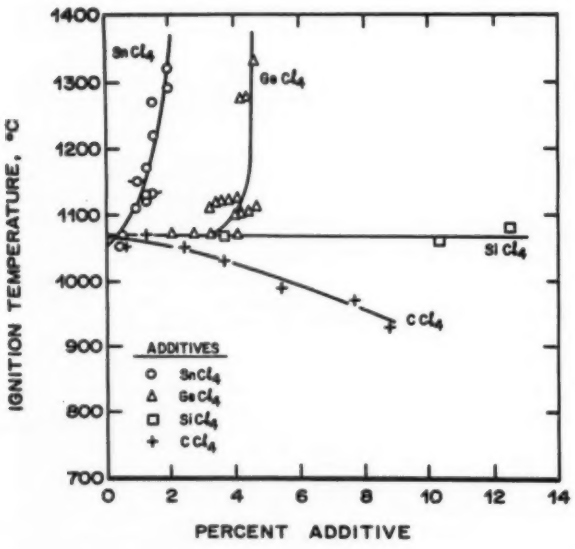

Figure 1. Effect of Group-IVa chlorides on the hot-wire ignition temperature of stoichiometric propane-air (21% O_2) mixtures.

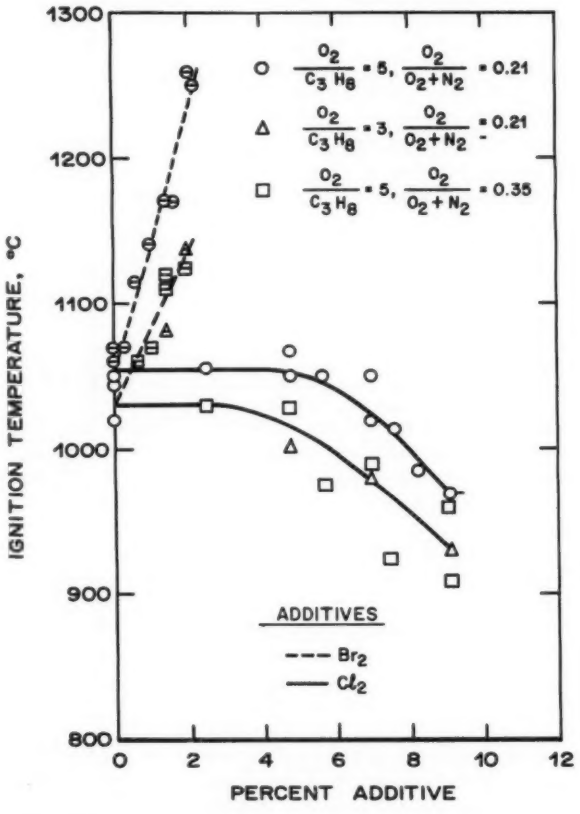

Figure 2. Effect of Br_2 and Cl_2 on the hot-wire ignition temperature of propane-air mixtures.

velocity inhibitors; whereas in the above tests CCl_4 actually tended to decrease the ignition temperature. It was noted that the effectiveness of the inhibitors toward ignition correlates inversely with their order in the periodic table, i.e., $SnCl_4 > GeCl_4 > SiCl_4 > CCl_4$; which, with the notable exception of CCl_4, is related directly to the bond energy for chlorine to the central atom of 76, 81, 91 and 78 kcal/mole, respectively. It might therefore be postulated that the inhibiting action is related in some way to the ease with which the chlorine is removed from the compound. This supposition, however, does not seem capable of withstanding the light of more searching analysis. If the additive serves merely as a source of chlorine atoms which react with the hydrocarbon to form hydrogen chloride, which, in turn, reacts with hydrogen and hydroxyl radicals to form H_2 and H_2O respectively, thus generating more chlorine atoms, then CCl_4 should behave in the same manner as $SnCl_4$ and $GeCl_4$ and have an effect intermediate between the two. The same conclusion would apply to the case of stripping reactions:

$$MCl_4 + H \rightarrow MCl_3 + HCl \qquad (1)$$

where M = Sn, Ge, Si or C. In fact, of course, CCl_4 is an ignition promoter. In this its behavior resembles that of the chlorine molecule itself (Figure 2). The action of CCl_4 on the ignition process appears to be quite definitely related to its role as a source of chlorine atoms, and its promotion mechanism must be the same as that of the chlorine molecule. Furthermore, they seem to have about the same effectiveness, i.e., 9% of either additive reduces the ignition temperature by about 150°K. Thus one can suppose that the influence of the metal chlorides on the ignition process is completely different from that of CCl_4, and that the correlation of their effectiveness with bond strengths is fortuitous.

A somewhat more satisfying explanation may be proposed for the effect of methyl halides on the ignition of propane-air mixtures (Figure 3). Their order of effectiveness as ignition suppressants is $CH_3I > CH_3Br > CH_3Cl > CH_3F$, the last acting virtually as an inert diluent. This is identical in manner to their action as burning velocity inhibitors. (2) Their influence correlates inversely in a well-behaved fashion with their bond energies $E(CH_3I) = 51$

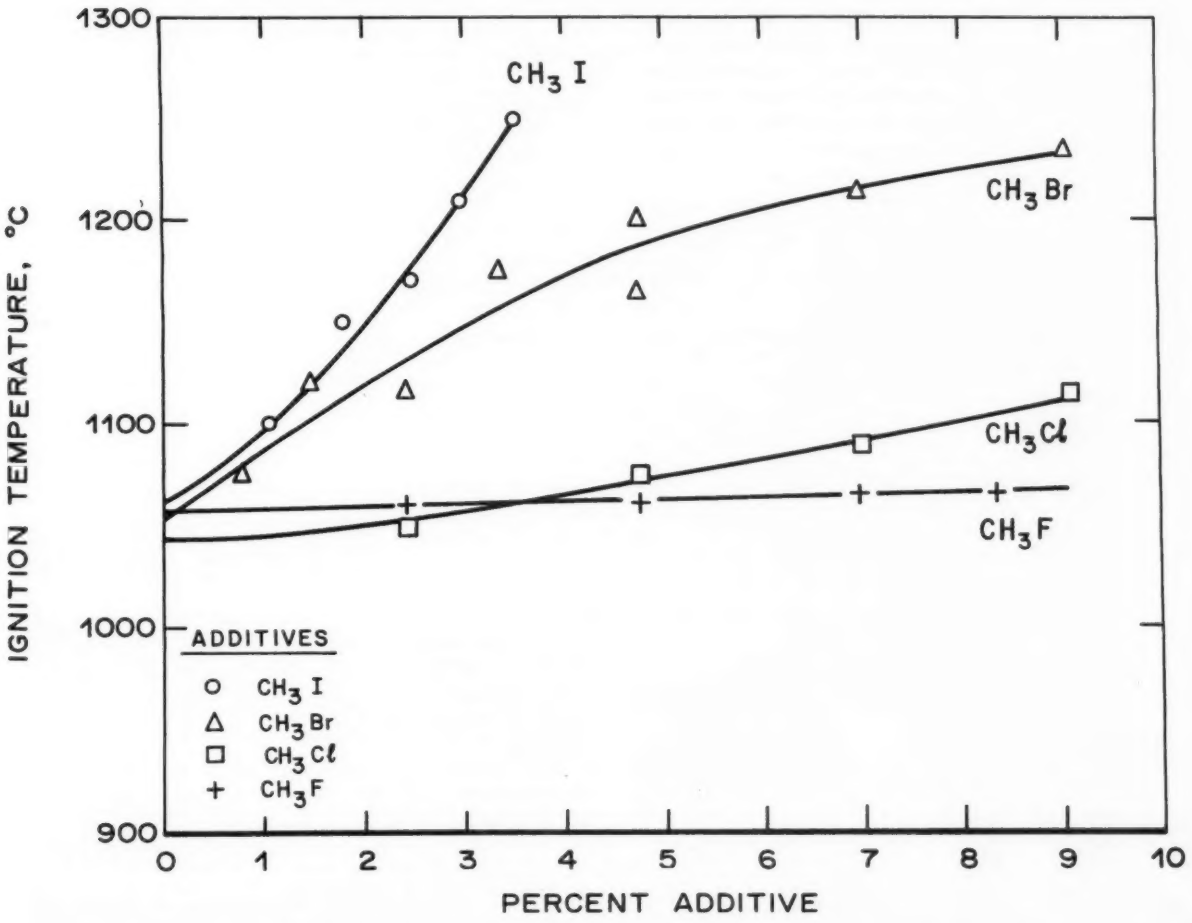

Figure 3. Effect of methyl halides on the hot-wire ignition temperature of stoichiometric propane-air (21% O_2) mixtures.

$< E(CH_3\text{-}Br) = 67 < E(CH_3\text{-}Cl) = 78 < E(CH_3\text{-}F) = 107$ kcal/mole. If one supposes that the inhibition reactions of importance are:

$$CH_3X + H \rightarrow CH_3 + HX \quad (2)$$

$$CH_3X + OH \rightarrow CH_2X + H_2O \quad (3)$$

followed by

$$HX + H \rightarrow H_2 + X \quad (4)$$

$$HX + OH \rightarrow H_2O + X \quad (5)$$

then one would expect the reaction rates for (2) and (3) to fall into the order $I > Br > Cl > F$. Furthermore, since the bond strengths for HX also fall in the rank $I < Br < Cl < F$, the relative rates for reactions (4) and (5) would follow the same pattern. In the case of HF, moreover, reaction (4) would be endothermic by about 30 kcal and highly unlikely. For HCl, this reaction would be thermally neutral and not too significant. Thus, it might be expected, upon the basis of these considerations, that CH_3F is apt to act like an inert diluent and CH_3Cl to have a very small effect on the ignition process, exactly the behavior observed. Though a detailed mechanism for the influence of methyl halides on the ignition of propane-air mixtures cannot be advanced upon the basis of the present experiments, it does appear that they inhibit the ignition process by removing H and OH atoms, thus reducing the rate of the chain branching reaction (6) and the hydrogen abstraction reaction (7)

$$H + O_2 \rightarrow OH + O \quad (6)$$

$$RH + OH \rightarrow R + H_2O \quad (7)$$

These experiments at ARL have provided valuable information regarding the influence of burning velocity inhibitors on the ignition of propane-air mixtures, and insight into possible mechanisms for their action. Future hot-gas ignition studies and shock-tube ignition delay measurements should yield even more definitive data relative to that mechanism, and may eventually provide better fire suppressants or ignition promoters for future U.S. Air Force applications.

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Dr. Scheller started working for the Air Force as a physical metallurgist in 1939. His interest in German developments in missiles turned his attention to rocket power plants and propulsion chemistry in general, resulting in his transfer to ARL in 1951.

Dr. Scheller's present research is concentrated on the investigation of kinetic mechanisms in flames and detonations, and the study of energy transport in reacting gases. He is an active member of the Combustion Institute, and was formerly active in the American Rocket Society, AICAT and other professional societies. He has also served as a member of the NACA Subcommittee on Combustion. Dr. Scheller has a considerable number of publications to his credit.

nonparametric techniques in statistical inference

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Many studies of data from a statistical point of view, involve a finite number of parameters and a known or assumed distribution of the data. In fact, the layman who is aware of such basic statistical terms as mean, median and mode might also be aware of the normal distribution function and all its "nice" properties. Procedures of study for problems involving families of distributions, indexed by a finite number of real parameters, are known as parametric procedures. However, the state of nature is not always so simple as to allow us to index parameters in this way, or to assume that the distribution is normal, or perhaps of some other known form. It is to these more general problems that nonparametric techniques must be addressed. A clear-cut definition of nonparametric theory is not available because of the various interpretations and explanations of the term. However, it is commonly agreed that the purpose of nonparametric theory is to provide a statistical treatment of the standard problems under quite general assumptions.

Most classical statistical information procedures are based on assumptions concerning the probability properties of the observational data used in their application. However, the accuracy of the probability information, obtained from any statistical procedure, depends on how closely the assumed and the actual properties agree. Statistical procedures whose approximate validity is not difficult to verify seem desirable. This is one of the advantages of nonparametric procedures. Research in the field of nonparametric statistics is motivated by the desire to broaden the range of the validity of inferences and, at the same time, to retain optimality. The field of nonparametric inference has experienced a rapid expansion in the last two decades, during which many new and significant results have been achieved. Areas in which nonparametric research has been quite active include the testing of hypotheses (in the univariate as well as multivariate models), point estimation as well as interval estimation, selection and ranking, sequential procedures and decision theory.

Because of the increase of research activities in the nonparametric area in the past few years and recent significant research results, the First International Symposium on Nonparametric Techniques in Statistical Inference was held with AFOSR support at Indiana University in Bloomington, Indiana, from 1 to 6 June, 1969. This was made possible through a grant from the Mathematics Division of AFOSR. Professor Madan Puri of the Department of Mathematics, Indiana University was the principal investigator, and Chairman of the organizing committee for the Symposium. The author of this article served on the organizing committee and was the point of contact for AFOSR.

The Symposium attracted leading international statisticians and mathematicians in the area of nonparametric inference who presented recent research results and indicated important research paths for the future. In addition to the 31 invited papers that were presented and discussed at the Symposium, many informal discussions were held between invited speakers and the large cross section of attendees at the Symposium. The Symposium was well attended, with 131 people officially registered representing industry, government and the universities. Principal topics highlighted during this symposium were nonparametric estimation, robustness, isotonic estimation, rank order theory, order statistics, goodness-of-fit, classification problems, sequential analysis, paired comparisons, and general theory. The proceedings of the Symposium will be published by a commercial publisher and should be available within a year's time.

Nonparametric procedures, as discussed at this Symposium, admit a great variety of applications in practical problems and many problems of Air Force interest. For example, the nonparametric procedures can be employed in communication theory for signal-detection problems whenever the underlying signal and noise distributions are unknown. This can occur, for example, in a jamming and countermeasures environment, or possibly in less hostile circumstances, where the lack of physical knowledge, or *a priori* knowledge of physical considerations, indicates uncertainties in data statistics in a temporal or spatial sense.

The study of nonparametric procedures in such problems arising in communication theory offers great promise of improved performance under the circumstances stated above. An initial study has established that nonparametric detectors can be uniformly better than parametric detectors for certain classes of Gaussian noise. Other areas of application of nonparametric techniques discussed at this Symposium include biometrics, physics, economics and industry. The talks and discussions at the Symposium and the Proceedings to be published represent a comprehensive cross section of current research in nonparametric inference. They should help to promote and enrich this field as well as contribute to the problem-solving techniques for many statistical problems of interest to the Air Force, other DOD departments, and other Government agencies.

THE BOUNDARY-LAYER TRANSITION MAZE

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In a classic paper entitled, "Fluid Motion with Very Small Friction," read before the Mathematical Congress in Heidelberg, Germany in 1904, Dr. Ludwig Prandtl disclosed his "discovery" of the boundary layer. He pointed out that the fluid flow about a solid body can be divided into two regions: a very thin layer adjacent to the body (the boundary layer) where friction plays an essential part, and the remaining region outside this layer, where friction may be neglected. With the aid of this hypothesis he was able, for the first time, to explain observed experimental phenomena. This important development was followed by many years of boundary-layer research which produced many acceptable solutions to fluid-dynamic problems; yet complete solutions to many physical problems pertinent to modern-day technology are still lacking.

Historically, one of the subsequent developments of considerable significance was the discovery that the magnitude of aerodynamic forces and moments and heat-transfer rates are critically dependent upon the state of the boundary layer (i.e., laminar or turbulent). Thus, much attention has been directed toward obtaining an understanding of the basic features of laminar and turbulent boundary layers. Since the effects of a turbulent boundary layer are considerably different from those of a laminar boundary layer* it becomes very important to understand the flow conditions which will produce a transition from a laminar boundary layer to a turbulent boundary layer.

Although boundary-layer transition has been investigated for many years, the fundamental nature of turbulence is little understood today. The result is that engineering decisions involving transition are based almost entirely upon empirical knowledge. Although such a situation is not necessarily bad, in the case of transition there exists many apparent inconsistencies of data that result in confusion as to the "appropriate" transition Reynolds number to use. A major difficulty in the interpretation of transition experiments stems from the fact that many parameters influence transition (e.g., Reynolds number, Mach number, surface roughness, boundary-layer cooling or heating, angle of attack, pressure gradients, entropy gradients, nose radius, mass addition, turbulence level in the tunnel fluid, noise generated from the tunnel wall boundary layer, etc.), and it is difficult to isolate and evaluate a *single* parameter. The result is that when one is confronted with the problem of predicting transition for a new configuration under a new set of conditions, he must attempt the difficult job of unscrambling the various effects. In principle, such unscrambling is possible; however, the situation is usually hindered by inadequate information. The problem involved becomes clear when one tries to correlate transition data, since a wide variety of trends are available to the correlator, and the results are influenced by the data chosen and the desires of the correlator. For example, over the past 20 years numerous transition curves, of the type shown in Figure 2, have appeared in the literature. Typically, what happens is that the laboratory experimenter obtains his new transition data, then proceeds to select from references those data which will permit him to draw a curve in some preconceived manner. The unfamiliar reader is then led to believe that things are finally getting well in hand, and now we understand boundary-layer transition. These published trends of boundary-layer transition Reynolds number with Mach number are of limited value to the vehicle designer and may, in fact, influence him in such a manner that he unnecessarily "over-designs" his vehicle. These trends are more or less uniquely related to the laboratory facility they were obtained from, and cannot be directly related to a flight prediction. Transition Reynolds numbers for flight vehicles may be as much as an order of magnitude larger

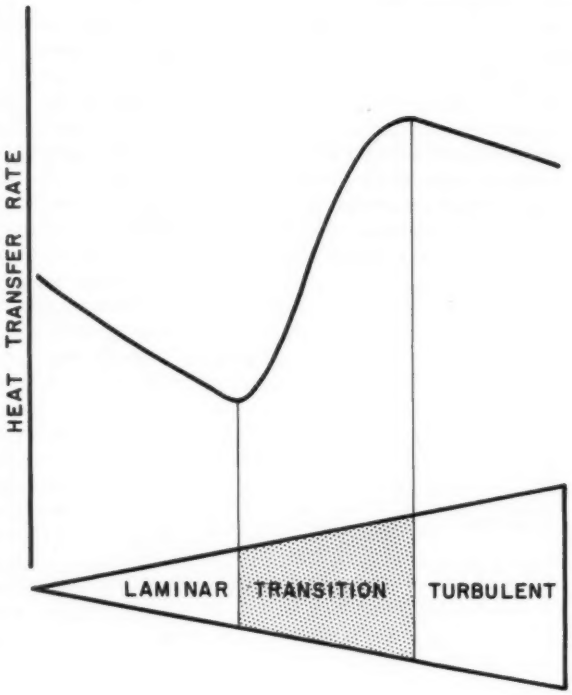

Figure 1. A schematic representation of the heat-transfer rate along the surface of a cone when the boundary layer undergoes transition to turbulence.

**For example, the heat-transfer rate may increase in magnitude between a factor of 2 to 10 when the boundary layer changes from laminar to turbulent. Figure 1 schematically shows the variations in heat-transfer rate along the surface of a cone when the laminar boundary layer undergoes transition to turbulence.*

than corresponding Reynolds numbers obtained with laboratory models.

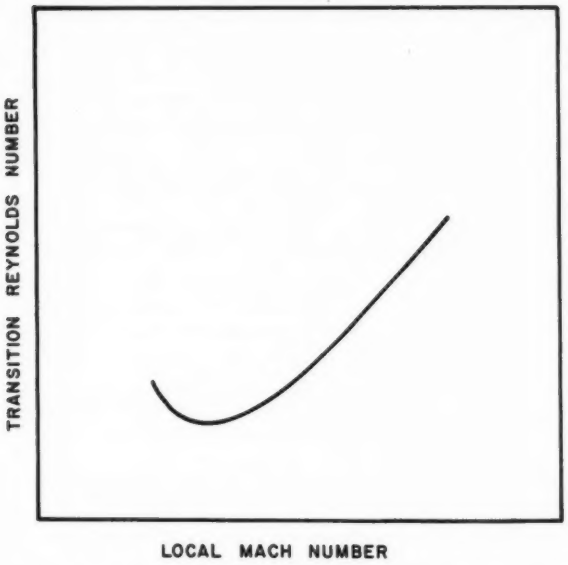

Figure 2. A schematic representation of the variation of transition Reynolds number with Mach number.

In order to illustrate the problem involved, a collection of transition data are shown in Figure 3. These data are only a portion of the mass of data available in the literature; however, it is believed to be an adequate sampling to illustrate the problems involved. Most of the

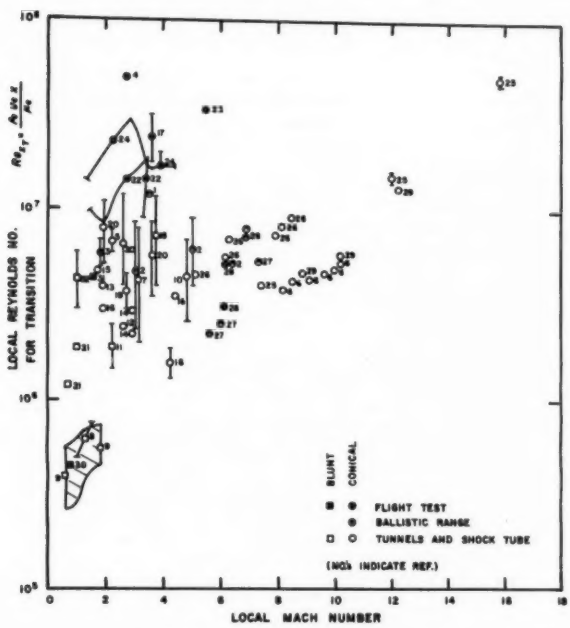

Figure 3. Boundary-layer transition data.

data in this figure were obtained on sharp cones, and are plotted as a function of two parameters: local Reynolds number (based on properties at the outer edge of the boundary layer and a distance along the surface), and local Mach number. These data were obtained from free-flight rocket tests, ballistic ranges, wind tunnels, shock tunnels and shock tubes. The very large variations of these data are due to the fact that variables, such as angle of attack, boundary-layer cooling, noise generated from the tunnel wall boundary layer, etc., are influencing transition, but are not identified in this figure. Unfortunately, it is not possible at this time to separate the various effects and offer the vehicle designer a realistic set of transition curves. Engineering decisions should be made only after a cautious assessment has been made of a number of sources of information. Transition design information should be frequently reassessed and updated.

Following are some general observations and comments pertaining to the prediction of boundary-layer transition:

(1) Transition on slender cones generally occurs at higher Reynolds number in free flight than in the laboratory. Flight transition Reynolds numbers (based on length) may be an order of magnitude larger than that obtained in wind tunnels.

(2) Laboratory transition experiments are valuable for detailed investigations of trends and the effects of the various parameters; but the specific numbers obtained should not be related directly to a flight situation.

(3) The published trends of large increases in transition Reynolds number with Mach number appear to be a characteristic of laboratory facilities and not a general boundary-layer stability feature. In fact, there is some evidence that transition Reynolds number is only weakly dependent upon Mach number.

(4) A limited amount of hypersonic transition data indicates that free flight and laboratory data are converging at high Mach numbers, thus being in closer agreement than at supersonic Mach numbers.

(5) Transition occurs much earlier on highly cooled blunt bodies than on sharp-tipped slender configurations.

(6) A "practical" configuration for hypersonic flight may often be a slender body with a small leading edge or tip bluntness. The large differences between transition on a highly cooled blunt body and a hypersonic slender body require that both transition criteria be applied in order to determine when and where transition will first occur on a slender configuration with small bluntness. For instance, situations may arise in which transition first occurs in the leading-edge region, resulting in an apparent "instantaneous" change from laminar to turbulent flow over the entire vehicle. In other cases, transition may first occur in the rear portion of the vehicle and, if higher Reynolds numbers are experienced, the flow would then be tripped by the nose region. The onset of ablation on the leading edge may enhance early transition in this region.

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Mr. Kenneth F. Stetson became a Group Leader in ARL's Fluid Dynamics Facilities Research Laboratory in August 1969. His association with the Air Force dates back to World War II, when he served as a pilot. Later, he attended the University of Maine and earned his B.S. in Engineering Physics in 1949. Recalled to active duty in 1950 he was assigned to the Wind Tunnel Branch of the Aircraft Laboratory at WPAFB, and the Fluid Dynamics Branch, ARL. During this time, he worked for his M.S. in Aeronautical Engineering, which he received from the Ohio State University in 1956. Also, he was graduated from the Air Force Institute of Technology (Aeronautical Engineering in 1952, and took engineering courses at M.I.T. and Northeastern University. After separation from service in 1955, he stayed on at ARL for a year as a civilian.

From 1956 to 1968, Mr. Stetson worked at the AVCO Everett Research Laboratory and the AVCO Missile Systems Division as a Senior Staff Scientist in the area of reentry problems. After returning to ARL in 1968, he concentrated his research on the study of boundary-layer problems.

canine hip dysplasia*

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A contribution toward solving a major problem of the Armed Services and other organizations using German Shepherd dogs is being made with AFOSR support by Dr. George H. Cardinet, III of the Neuromuscular Research Laboratory, College of Veterinary Medicine, Kansas State University, Manhattan, Kansas. The problem is hip dysplasia, which affects many of the German Shepherd breed, and is responsible for about 78% of the medical rejections for sentry-dog training. The Air Force is sole manager for the Department of Defense in this area and purchases German Shepherds world-wide to satisfy DOD requirements. The ultimate goal of this research is to obtain the necessary information to provide a genetic base for breeding dogs free of hip dysplasia.

Hip dysplasia in dogs is a hereditary disease which results in the abnormal formation of the hip joint. It is a common disease in large dogs, particularly the German Shepherd. The abnormal formation of the joint results in a looseness which allows extreme movement between the head of the femur and the acetabulum of the pelvis. The schematic drawing in Figure 1 illustrates the normal anatomy of the hip joint. With the disease, where the movement within the joint is extreme, two changes occur. First, the ball or head of the femur becomes flattened and irregular. Second, the socket or acetabulum becomes shallow. The end result is that the joint may become dislocated to a varying degree. With the extreme movement and dislocation, the bony surfaces of the joint rub against each other. This sets up an inflammation or irritation in the joint which eventually leads to an arthritis and impairment of the animal's ability to do work.

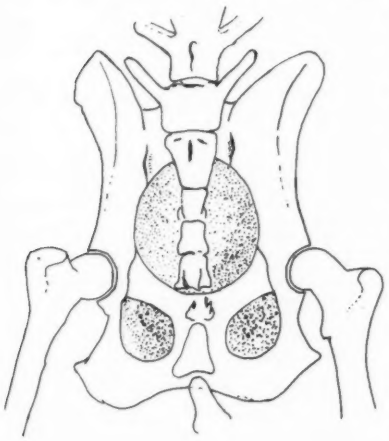


Figure 1. Normal anatomy of the hip joint.

Figure 2. X-ray of a dog with hip dysplasia.

Figure 2 is an X-ray of a dog with hip dysplasia. Note that the head of the femur is not rounded and has flattened surfaces. Also, the acetabulum is shallow and the head of the femur is not seated deep within the socket.

The practical problem that faces users of working dogs, such as the Armed Services for sentry or patrol dogs, or the blind for seeing-eye dogs, is the early identification of dysplastic dogs. Currently, diagnosis is dependent on X-ray examination and, in many cases, it is not possible to detect afflicted dogs until they are 6-12 months of age. At this age, the user of working German Shepherds has invested time and money in training the dogs as well as the personnel who will use them.

It is difficult to show the effects of hip dysplasia in a photo. However,

Research described in this article is being performed by Dr. George H. Cardinet, III, D.V.M., Ph.D., Assistant Professor of Anatomy, Dr. Larry J. Wallace, D.V.M., M.S., Associate Professor of Surgery and Medicine, Dr. Marion R. Fedde, M.S., Ph.D., Associate Professor of Physiology, and Dr. Mark M. Guffy, D.V.M., M.S., Assistant Professor of Radiology, all of the Neuromuscular Research Laboratory, Department of Physiological Sciences, College of Veterinary Medicine, Kansas State University, Manhattan, Kansas.

Figure 3.

Figure 4.

Comparison of a normal two-year old German Shepherd (Figure 3) with a two-year-old German Shepherd which has an extreme case of hip dysplasia (Figure 4).

the reader may compare the photo of a normal two-year-old German Shepherd (Figure 3) with a two year-old German Shepherd (Figure 4) which has an extreme case of hip dysplasia. The most recognizable conformational changes here are the curvature of the back and "down-in-the-hips" appearance of the latter animal. This stance is the result of the dog's assuming a posture which causes the least pain to the hip joints. Such a dog has little potential use as a sentry or patrol dog.

There have been numerous studies conducted in the past 10-15 years on hip-dysplasia; however, to date, the underlying cause or causes of the disease have still not been identified. In fact, the mode of its inheritance still remains to be determined. Without a basic understanding of the etiology of the disease or its mode of inheritance, one is hardly in a good position to control it.

The research program of the Kansas State group offers several new concepts concerning the development of hip dysplasia. It proposes to investigate the role of a muscle disease in the development of hip dysplasia, and is specifically interested in a single muscle—the pectineus. This muscle is an adductor, i.e., it pulls the legs toward the midline much like a human pulling his knees together. It is connected at its origin on the pelvis and at its insertion on the femur. Interest in this muscle stems from the fact that many puppies, when laid on their back under anesthesia, cannot fully abduct their hind legs, i.e., their legs will not fully fall away from the midline. In such puppies, the restriction in abduction appears to be due to a tautness of the shortening pectineus muscle.

In Figure 5, the legs of a puppy are being abducted under anesthesia. Note the tautness of the pectineus muscle which restricts further abduction (muscle bulging at end of pen). These clinical observations have suggested that the pectineus muscle may be abnormal. When these muscles were examined by histopathologic and histochemical means, a lesion was observed in a high percentage of puppies.

Figure 6 shows a section of pectineus muscle from a normal puppy. This histochemical preparation for myosin-adenosine triphosphatase (ATPase) illustrates the two types of muscle cells normally found in muscle. The Type-I cells are light in color, and the Type-II cells are dark in color. These cell types differ in their chemical composition and in their physiological contraction properties.

Figure 7 shows a section of abnormal pectineus muscle. The magnification is the same as in Figure 6. The lesion involves Type-II muscle-cell atrophy, i.e., an abnormally small size of the dark-staining muscle cells. This change is characteristic. The etiology or cause of this lesion is not known, and is currently being investigated.

Figure 5. The legs of a puppy being abducted under anesthesia.

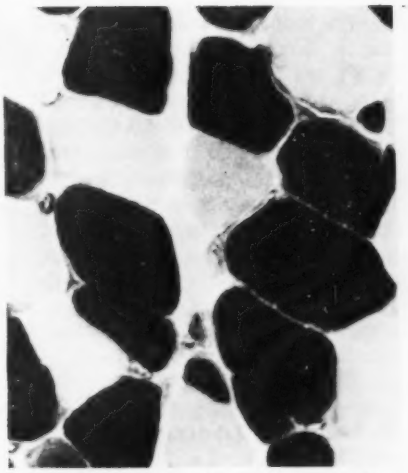


Figure 6. A section of a pectineus muscle from a normal puppy.

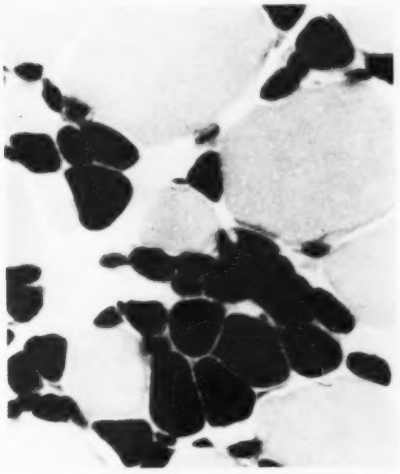


Figure 7. A section of abnormal pectineus muscle.

The change may be due to an abnormality of the muscle cells themselves, or to abnormalities of the nerve cells which innervate these muscle cells.

The profound effect this lesion can have on a muscle is illustrated in Figure 8. Actually, both muscles shown proved to be involved when examined microscopically; but the extent of the lesion was greater in the left pectineus muscle, with its weight roughly 50% of that of the muscle on the right. In severe cases, the cellular atrophy produces an atrophy of the whole muscle.

During foetal and early life, bone has a considerable capacity for modeling, and can undergo changes in shape. The line of investigation proposed by Dr. Cardinet is to study the effects of this muscle lesion on the abnormal shaping of the head of the femur and the acetabulum in hip dysplasia. The anatomical relationship of this muscle to the hip joint is such that a shortening of the pectineus muscle could cause the bony changes observed in hip dysplasia.

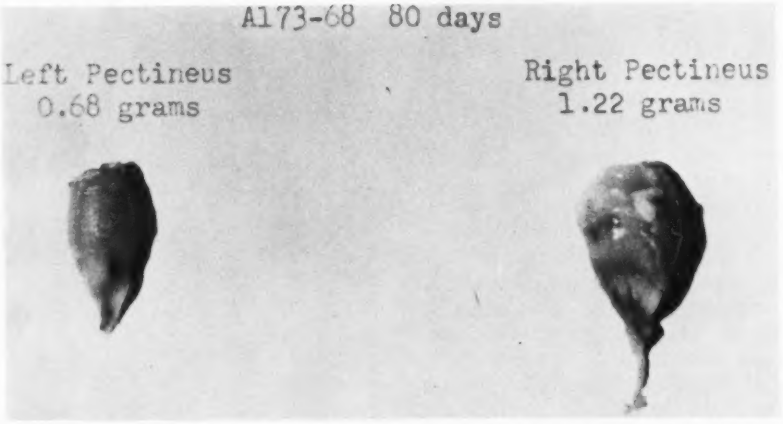


Figure 8. The effect of a lesion on a muscle. The extent of lesion is greater in the left pectineus muscle, with its weight about 50% of the muscle on the right.

BIG JETS and airport meteorological instruments

AEROSPACE INSTRUMENTATION LABORATORY, AFCRL

The new generation of jet aircraft that will be coming into service in the 1970's—the 747, the Trijet Airbus, the C-5A, and the SST—may cause a significant modification of weather conditions at the airfields from which they operate. This prospect is considered in a paper recently presented at the Air Force Academy by Andrew S. Carten, Jr. of AFCRL, who considers the implications of big jet operations, both from the standpoint of airport meteorological instruments and the standpoint of aircraft operations.

The big jets will be powered by huge engines whose thrust values (40,000 to 50,000 pounds) will be more than twice as high as those of today's standard transports and bombers. In addition, the very bulk of these planes will produce considerably greater slip-stream flow as they move through the air. These two factors will create intense localized wind gusts, long-lasting pockets of violent low-level turbulence, and reservoirs of abnormally warm air which could affect smaller aircraft using the same airfields. Also, airport meteorological instruments may not accurately reflect general airport conditions since their readings may easily be distorted by the jet-exhaust wakes of taxiing aircraft.

In his paper, Carten attempted to forecast the type of ground-based meteorological equipment needed for the 1970's. In the process, he took a critical look at existing meteorological sensors and their deployment at airports. He then reviewed a multitude of new sensing techniques on the near and far horizon that could provide more precise and more representative information on airport meteorological parameters.

One example concerns the transmissometer, a standard instrument for measuring runway visibility. The transmissometer measures the extinction coefficient of light over a 500-foot-long horizontal path. Usually, a single transmissometer is used, and its reading is taken as being representative of conditions along the whole runway. Big jets, which could alter local visibility conditions, may force a multiple deployment of transmissometers. In any event, better transmissometers are needed because present transmissometers are least sensitive under poor visibility conditions—when high sensitivity is most necessary. Carten mentions a scatter measurement device under development by AFCRL as a possible replacement sensor.

Carten's paper also stresses the need for renewed emphasis on the slant-range visibility measurement problem. He cites the relatively poor pitch response of the big jets as an urgent reason for improving the quality of the visibility information furnished to pilots landing these aircraft.

Carten also stresses the need for better wind information at landing-approach altitudes. There is now no practical method for obtaining continuous data on a vertical cross section of winds and wind shears from the ground level up to about 1,500 feet along the aircraft landing-approach path. A potential technique for obtaining such data is the Doppler detection of natural atmospheric aerosols or of aerosols artificially released into the region.

Carten cautions against the introduction of VTOL (vertical-takeoff-and-landing) and STOL (short-takeoff-and-landing) aircraft into the general mix of aircraft at air bases. Because of their slow takeoff and landing speeds, the VTOL and STOL aircraft are particularly sensitive to gusts and turbulences of the kind that will be created by giant jets. Carten therefore suggests that it may be inadvisable to operate VTOL and STOL aircraft from airports that may have a heavy traffic in giant jets.

The Carten paper covers the spectrum of meteorological instruments used at airports, both for general meteorological observations and for airport operations. It also emphasizes that more attention be given to their deployment to achieve representative readings. New instruments under development at AFCRL and elsewhere—weather, radar, radiosondes, lightning-warning devices, rain gauges, and so on—promise a sizable change in both the kinds and quality of airport meteorological instrumentation during the 1970's.

Mr. Andrew S. Carten, Jr., has been with AFCRL's Aerospace Instrumentation Laboratory since 1960 where he is a Senior Engineer for Meteorological Equipment, and Chief of the Equipment Engineering and Evaluation Branch. He is responsible for the Laboratory's exploratory-development program in meteorological instrumentation. Many of these sensors—anemometers, transmissometers, and humidity sensors, will eventually find their way into the Air Force inventory.

After receiving his B.A., cum laude, from Holy Cross College in Worcester, Massachusetts, in 1943, Mr. Carten, in the same year, was graduated from the USAAF Weather Officers' School at Grand Rapids, Michigan. In 1947, he obtained his M.S. in Chemistry from Tufts University and from 1947-1949, studied industrial and electrical engineering at night at Johns Hopkins University.

Before joining AFCRL, Mr. Carten served as a Staff Weather Officer with the Eighth Air Force during World War II, and as an engineer with the Bendix Corporation until 1954. In that same year, he joined the Air Force Cambridge Research Center (predecessor of AFCRL) as Chief, Design Engineering Branch, Atmospheric Devices Laboratory.

new lunar laser observatory placed in operation

TERRESTRIAL SCIENCES LABORATORY, AFCRL

Laser range-finding equipment, installed June 1969 at AFCRL's new Lunar Laser Observatory, is now making continuous observations. The AFCRL Observatory, located 40 miles north of Tucson, Arizona, was built specifically for lunar laser ranging experiments; its construction was funded largely by NASA. From the Observatory, a high-power laser light pulse is directed toward special reflectors placed on the moon by the Apollo astronauts.

The laser ranging equipment is designed to measure distances to the moon with a precision never possible before. Lunar distance is measured by timing the round trip of the laser pulse, using a cesium clock. The measurements have an accuracy of 10 billionths of a second, corresponding to 1.5 meters in range. Hence, earth-moon distances can now be accurately measured to within 4 to 5 feet, compared to the previous accuracy limit of hundreds of feet.

The 28-day lunar orbit, although approximately circular, varies in distance from the earth by about 14,000 miles, with the lunar apogee being

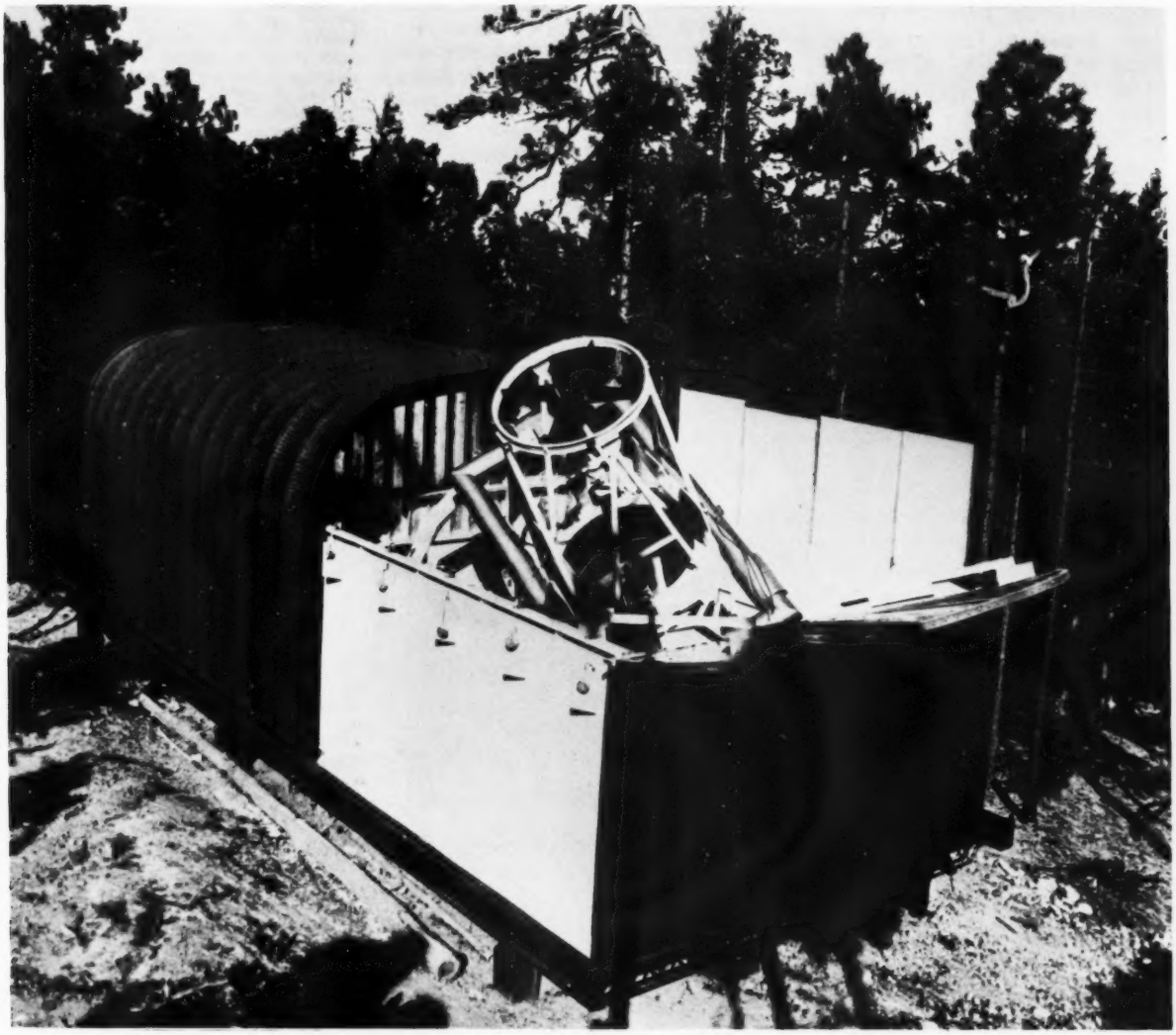


Figure 1. AFCRL's lunar laser telescope, which has a 60-inch lens, is used both to transmit the laser pulse and to receive it after deflection from the reflector array placed on the moon by the Apollo-11 astronauts. The small AFCRL Observatory, located 40 miles north of Tucson, was funded in part by NASA.

252,750 miles. By measuring the moon distance over many orbits, the orbit can be highly refined. Even more important, we can learn much about the earth. The laser-lunar experiment permits us to measure the position of the telescope with respect to the earth's axis of rotation. Thus, any apparent variation of this position indicates a wandering of the earth's axis. France, Russia, and several U.S. observatories are establishing stations simular to the AFCRL station. A distribution of such stations will permit measurements of the rate of continental drift.

The AFCRL program is under the direction of Dr. Donald H. Eckhardt, with Robert L. Iliff and Mahlon S. Hunt (Chief of the AFCRL Lunar Laser Observatory) as co-investigators. The laser rangefinder, built and installed by the Hughes Aircraft Company, is attached to a 60-inch optical telescope at the observatory.

The brief pulse of light from the 10-joule laser is only about 10 feet long. As it moves toward the moon, it spreads out, expanding to a diameter of 2½ miles by the time it reaches the moon. Part of this disc of light is reflected back to the telescope by the lunar reflector and is received 2.5 seconds later. The reflector array consists of 100 cube corner reflectors arranged on a pallet measuring about 2 square feet. The pallet was placed on the moon about 30 feet from the Apollo-11 landing module. Light striking the corner reflectors is always reflected back to its source.

During the lunar day, it is more difficult to detect the reflected signal immediately. During the lunar night, however, the reflectors return a sharp signal. The laser ranging system was tested even before the astronauts landed on the moon by reflecting laser pulses from the lunar surface. Although ranging information can be obtained without reflectors, such measurements would lack the desired precision.

Dr. Donald H. Eckhardt is a physicist with the Terrestrial Sciences Laboratory, AFCRL. He is currently investigating the size, shape, mass distribution, and librations of the moon, and is also a planetary and aerospace geodesy consultant in the applied mathematics of geodesy and gravity.

Dr. Eckhardt received both his degrees in Geophysics from the Massachusetts Institute of Technology, a B.S. in 1955, and a Ph.D. in 1961. Before joining AFCRL in 1963, he had worked for the Socony Mobile Oil Co. in the U.S. and Venezuela as a petroleum geologist and exploration geophysicist, and for the Wolf R & D Co. at Boston as a meteorological programming analyst. He has several papers to his credit.

Mr. Robert L. Iliff is a research physicist with the Terrestrial Sciences Laboratory, AFCRL. He is currently doing theoretical and experimental work with high-energy lasers as a geodetic tool.

In 1961, Mr. Iliff received his B.A. in Physics and Astronomy from Boston University. Prior to coming to AFCRL, he worked for the Arctic Institute of North America in Washington, D.C., and the Barkley and Dexter Laboratories, Inc., in Fitchburg, Mass. While with the Arctic Institute, he worked on the location of instruments to be installed on long-range aircraft to provide a better understanding of the earth's environment through the remote collection of geophysical data.

Mr. Iliff has several articles to his credit.

Mr. Robert L. Iliff (standing) and Dr. Donald H. Eckhardt have devoted much of the past two years to the planning of AFCRL's Lunar Laser Observatory. Mr. Iliff's specialty is the transmission of laser light through the atmosphere. Dr. Eckhardt specializes in selenodesy, which is defined roughly as lunar geodesy.

use of light pressure to measure weight

SPACE PHYSICS LABORATORY, AFCRL

An extremely delicate microbalance that can sense weight changes as small as 100 millionths of a gram and which can be restored to perfect balance again by the pressure of light has been developed by Drs. Karl P. Zinnow and Jens P. Dybwad of AFCRL. This is believed to be the first application of light pressure to weight measurement.

The light-pressure microbalance was a product of necessity. The best existing microbalances, although matching the performance of the AFCRL instrument, could not be used in the particular experiment for which the light-pressure microbalance was designed. (The experimental problem leading to the development of the light-pressure microbalance was that of measuring the weight added (or subtracted) to a target bombarded by protons.) Most existing microbalances use magnetic techniques for restoring the balance and thus cannot be used when interfering magnetic fields are present.

The microbalance was built for operation in a 200-liter chamber evacuated to 10^{-11} torr. The apparatus itself (See Figures 1 and 2) looks like a small, extremely delicate glass mobile. Various elements are suspended by almost invisible thin tungsten wires. The balance beam is a glass rod 18 cm (about 7 inches) long. It sits astride a taut tungsten wire (or, more precisely, it is mounted at the center apex of a small, W-shaped glass spring which is pulled tight by torsion wires at each end). The torsion properties of the wire permit the balance beam to see-saw up and down.

Hanging down from each end of the balance beam is a 45-cm length of wire. At the end of the wires are the weight and counterweight. Touching one end of the balance beam imparts a slow up-and-down rocking motion whose periods of oscillations are adjustable to between 15 and 60 seconds.

The normal up-and-down excursion of the weight and counterweight is no more than 1/2 mm. Because the oscillation period may be relatively long—as much as 60 seconds—this motion is hardly noticeable. When weight and counterweight are balanced, the rocking balance beam crosses its horizontal position, the null, in equal and uniform increments of time. When weight is added to one side, the null is reached at unequal time periods.

To detect and time the null, a small vertical mirror is mounted at the center of the balance beam. (This glass assembly, consisting of the mirror, the balance beam, and the W-shaped spring has an ornamental, jewel-like appearance as light glints from the various surfaces.) The mirror tilts back and forth as the balance beam rocks up and down. Light reflected from the mirror detects and times these null crossings. It is possible to derive a measure of weight by simply timing the pattern of these null periods—but this direct measurement would not be very accurate. Nevertheless, as will be shown later, the timing of these periods is essential to the operation of the microbalance.

The device used to measure weight is an independently suspended mobile—one with a single element. Attached to the end of a 45-cm length of tungsten wire is a horizontal rod with a mirror at one end. By directing light to the mirror at the end of the rod, the suspended element can be deflected and will rotate by a few degrees.

The mirror at the end of the rod is the measuring mirror and is aligned to another mirror which forms one of the weights suspended from the balance beam. This balance-beam mirror is horizontal and faces downward. If the measuring mirror and the balance mirror are properly aligned, a beam of light can be reflected from the measuring mirror to the balance mirror and back again along a parallel path.

Now we are in the position to describe how the whole system works. The microbalance is set into motion, slowly oscillating up and down. When weight is added to one side of the balance, the null detector shows that the time between nulls is unequal. This information is used to regulate a variable intensity lamp which directs a beam of light to the measuring mirror. This light pressure deflects the measuring mirror out of alignment with the balance mirror. The measuring mirror is brought back to alignment by rotating the torsion tungsten wire, usually by a few degrees. Just enough light pressure is applied to the weight on the balance beam (applied, of

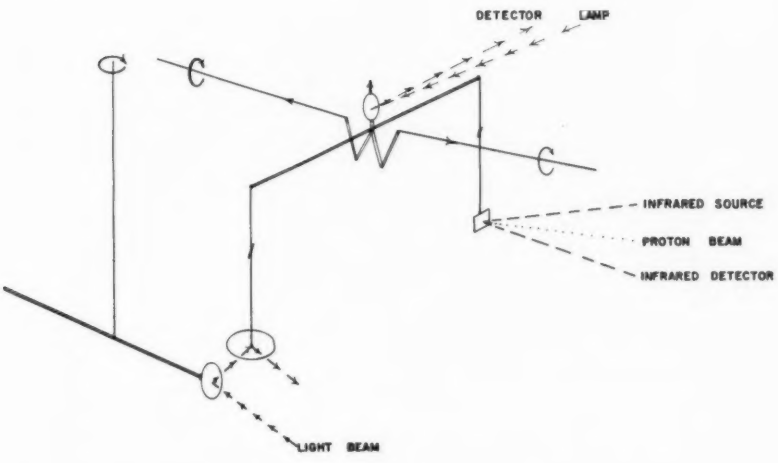


Figure 1. Schematic of the microbalance.

course, indirectly after first striking the measuring mirror) to compensate for the weight change and thus bring the system back into equilibrium. The amount of light pressure is regulated by the null detector and timing component. The light is pulsed so as to impart just enough push at the right time to sustain the oscillating motion of the beam.

Because the torsion properties of the tungsten wire holding the measuring mirror are known, the weight added to one side of the balance can be derived by measuring how much the wire must be rotated to compensate for the light pressure needed to restore the balance to equilibrium.

The system can measure weight changes of 10^{-8} gram over an interval of 40×10^{-8} gram. Although this range isn't as broad as that of other microbalances, the limit of 10^{-8} gram approaches the maximum feasible sensitivity of weight measuring in devices of any kind.

Dr. Karl P. Zinnow is a research general physical scientist in the Lunar-Planetary Research Branch of AFCRL's Space Physics Laboratory. He is presently conducting research on the physical and chemical effects of solar-wind bombardment on probable lunar and planetary surface materials in a simulated space environment.

Dr. Zinnow received his Diplom in Physik in 1963 and his Ph.D. in 1968—both from the University of Tuebingen, Germany. He has published several scientific articles.

Dr. Jens Peter Dybwad is a research general physical scientist at the Lunar-Planetary Research Branch of AFCRL's Space Physics Laboratory. He is conducting a research program to develop specific knowledge about radiation damage, ultra-high vacuum adhesion, and radiation-induced luminescence, and to develop new analytical methods and techniques to explore these phenomena. This program is part of a study on the effects of lunar and planetary environments on the probable surface materials to be found on these bodies.

Dr. Dybwad received his Diplom Vorpruefung in Chemistry in 1959 from the Technische Hochschule in Karlsruhe, Germany and, in 1966, his Ph.D. in Mineralogy from the Universitaet Tuebingen, also in Germany. He has published in the scientific literature, and is a member of the American Association for the Advancement of Science.

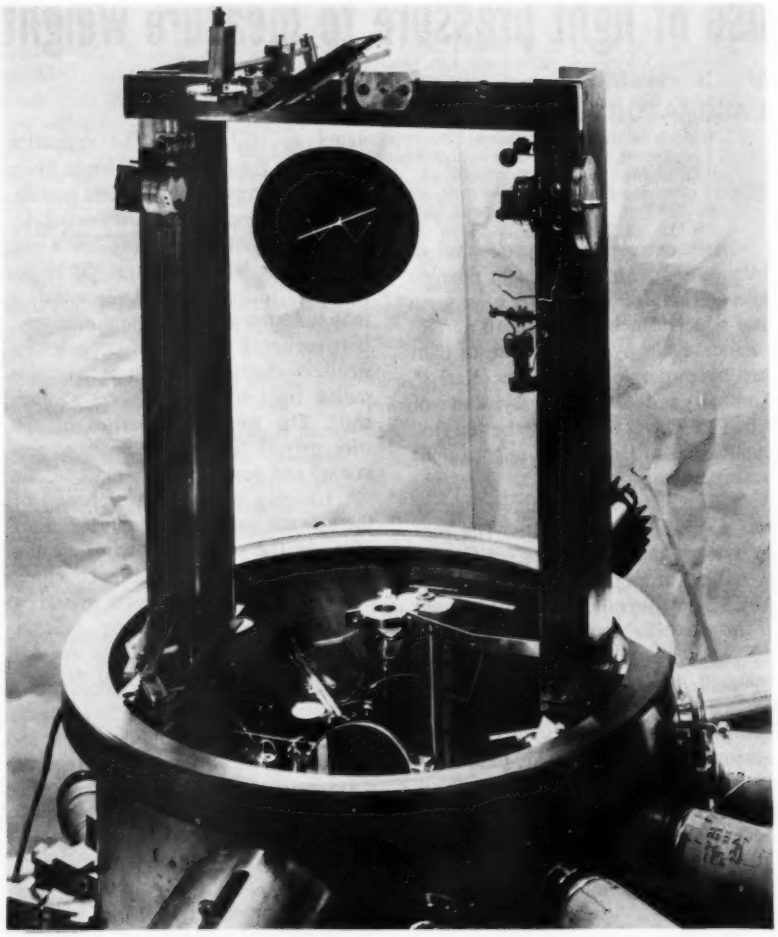


Figure 2. Photo of the microbalance and associated mirror arrangement. The cover of the vacuum chamber has been removed.

Dr. Karl P. Zinnow (left) and Dr. Jens P. Dybwad, designers of the microbalance. In the background is the cylindrical vacuum chamber in which the microbalance is placed.

large cuprous-chloride crystals promise to advance laser modulation

SOLID STATE SCIENCES LABORATORY, AFCRL

Since the first laser was fired in 1960, researchers have sought methods for modulating laser light to use in communications. In recent years, a number of modulating schemes have been described, and voice and picture information has actually been transmitted by laser light. Like most first steps, the achievements are noteworthy but tentative.

Two AFCRL chemists, Dr. Alton F. Armington and John J. O'Connor, have recently succeeded in growing large crystals of a highly promising modulator material—cuprous chloride. Although cuprous-chloride crystals have been grown by several other investigators, the crystals have been too imperfect for effective laser light modulation.

Most laser light modulation schemes use a transparent crystal as a modultor. The light output from the laser is passed through this crystal. If the transmission properties of this crystal can be readily altered by some external means, then one can modulate the light passing through the crystal. The simplest way to change the transmission properties of the crystal is to change its refractive index. There are a number of electro-optical effects available to do this. By using the Kerr or Pockels effect, for example, the refractive index of the crystal can be changed by simply applying an appropriate voltage to it. By changing the refractive index, phase changes in the light passing through the crystal are induced. In this way the laser light is modulated.

Cuprous chloride meets all the requirements of a good modulator crystal. It is transparent to light over a broad band of frequencies from 0.4 to

Dr. Alton F. Armington (right) and John J. O'Connor study the geometry of the special gel growth apparatus developed for growing pure, large-sized, cuprous-chloride crystals.

above 20 microns, and its refractive index is easily altered when a voltage is applied. It has a low dielectric constant, which a modulation crystal must have to reduce dielectric heating during operation. A further advantage is that it operates in a transverse, rather than in a longitudinal mode, making it possible to place the input-output connections on either side of the laser light beam rather than across its path.

Most researchers who have tried to grow cuprous-chloride crystals have used the Czochralski process in which the crystal is slowly drawn from a molten cuprous-chloride solution. Large cuprous-chloride crystals have in fact been grown by this method. But, as the crystal cools from the 420°C melting point of cuprous chloride, it undergoes severe strain due to a phase transformation at about 408° C; this strain produces internal fractures. The crystal cannot then be used as a modulator.

One way to overcome this problem is to grow the crystal at temperatures below the 408° C transition temperature. Armington and O'Conner have followed this procedure, using the silica-gel growth method. With this method, crystals are grown at room temperature, with growth taking place in a glass tube filled with gel. The growing crystals, embedded in the gel, are clearly visible throughout their one-month growth period.

The gel growth method depends on the slow transport of a solution through the gel to the site of the growing crystal on which the solution precipitates. The role of the gel is to reduce turbulence during the slow process of diffusion and growth.

The gel growth technique, as such, is not new; but Armington and O'Connor have introduced a number of refinements. Among these are methods for maintaining a uniform saturation level of the cuprous-chloride solution throughout the month-long growth period, and for maintaining a constant rate of diffusion of the solution through the gel. They solved these problems by complexing the cuprous-chloride solution with hydrochloric acid, and by defining the optimum rate at which the solution must be introduced into the gel from a special container. The size of the gel growth tube and the solution chamber are critical features.

With these procedures, Armington and O'Connor have obtained cuprous-chloride crystals of sufficient size and perfection to be used for laser light modulation. Their largest crystals are clear, transparent tetrahedrons with facets measuring 8 mm on a side. Both the optical properties and modulating capabilities of the crystals have been tested, with outstanding results.

Dr. Alton F. Armington, a research chemist in the Purification and Growth Branch of AFCRL's Solid State Sciences Laboratory, is conducting a basic and applied research program in the chemistry of the solid state. Emphasis is on electromagnetic phenomena associated with the preparation, crystal growth, and ultra purification of materials to meet Air Force requirements. Dr. Armington is recognized as one of the nation's leading chemists in the field of gel growth techniques. He received his B.A. in Chemistry from Boston University in 1950, his M.S. in Chemistry from Tufts College in 1951, and his Ph.D. from Pennsylvania State University in 1961.

Dr. Armington developed materials for floor coverings in 1952 while working for Congoleum-Nairn, Inc. From 1953 to 1954, he was concerned with problems related to low-temperature combustion and corrosion while employed by the Naval Research Laboratory. From 1954 to 1957, he worked on problems related to the structure and kinetics of carbon and graphite for Pennsylvania State University.

Dr. Armington has published more than 50 articles in various scientific journals, and is the recipient of several Invention and Special-Act Awards. He is a member of the American Chemical Society, Phi Lambda Upsilon, and RESA.

Mr. John J. O'Connor is a research chemist in the Purification and Growth Branch of the Solid State Sciences Laboratory, AFCRL. He is presently concerned with the preparation, ultrapurification, growth, and characterization of single crystals by means of reverse-direction electrodeposition techniques.

Mr. O'Connor received his S.B. in Chemistry from Harvard College in 1950. From 1950 to 1952, in the Department of Physical Chemistry of the Harvard Medical School, he investigated the interaction between proteins and heavy metal ions. He was employed by Tracerlab as a radiochemist from 1952 to 1963, where he was responsible for developing radiochemical analytical schemes.

Mr. O'Connor is a member of the American Chemical Society, and has published numerous articles in scientific journals.

new method for communicating through the plasma sheath

MICROWAVE PHYSICS LABORATORY, AFCRL

Mr. Daniel J. Jacavanco makes an adjustment on the instrumentation associated with a plasma jet used in studies for propagating radio signals through the plasma sheath.

A new technique for transmitting radio signals through the plasma sheath that envelopes space vehicles during reentry has been tested at AFCRL. The technique involves boosting the already elevated temperatures of the free electrons in the sheath to a higher energy level so that they will readily attach themselves to the heavier molecules in the plasma. Laboratory tests of the technique at AFCRL using an arc jet have been highly encouraging. The experimental program is discussed in the AFCRL report, "Electron Reduction in the Reentry Plasma Sheath" *(AFCRL-69-0154)* by Daniel J. Jacavanco.

The plasma sheath is responsible for that awkward 3 to 4 minutes of radio blackout during the reentry of manned space vehicles, a now familiar pattern. During reentry of the shuttle lifting body vehicles now being planned, the blackout period may last for 15 minutes or so. The plasma sheath is also a barrier to the development of jamming systems for ballistic missiles.

The reason that electromagnetic energy doesn't penetrate the plasma envelope surrounding the reentering vehicle is that the energy is absorbed by the free electrons. The free-electron density may exceed 10^{12} free electrons per cubic centimeter. The other plasma component, the positive ions, absorbs very little energy. Because of their light mass, electrons alone respond to the rapid variations of the EM signal, thus absorbing energy.

Of the many schemes that have been suggested or tried for propagating through the sheath, none is entirely satisfactory and none can be universally used for vehicles of all geometries, reentry descent rates, and reentry paths. Seeding the sheath with water or chemicals from special nozzles during reentry is only partially effective. It is possible to clear a propagation window through the sheath by applying a strong magnetic field; but the scheme is presently impractical because of the added weight. Still another scheme is to use microwaves or laser frequencies which are not absorbed by the sheath. This scheme would require a satellite relay station to convert the longer wavelengths from the ground stations to

the shorter wavelengths that can penetrate the sheath but not always the atmosphere.

AFCRL has investigated all of these techniques, and others as well. The new electron-depletion technique is the most promising of the many schemes that have been investigated. The principle is to raise the energy level of the free electrons in the plasma. At this higher level, the attachment rate is enhanced and far exceeds the collisional detachment rate. Once the electron is attached to the heavy particle, it cannot, because of mass, respond to the rapid variations of the electromagnetic field. The temperatures of the electrons are raised by the Luxemburg Effect in which a high-power radio-frequency signal is transmitted into the plasma and is absorbed by the electrons.

Laboratory tests at AFCRL were conducted using a d.c. plasma arc jet, with the plasma consisting of oxygen and nitrogen gases, both of which have a high affinity for electrons. The expansion nozzle was mounted in an evacuated chamber maintained at a pressure of 1 torr. The experiment approximates the atmospheric reentry conditions in temperature, ambient pressure, electron density and neutral species. Various RF heating frequencies and power levels were investigated. Although the optimum frequency-power combination varies with electron density and temperature, a power of about 20 watts and an RF heating frequency of about 7 MHz have given overall excellent results.

The AFCRL researchers believe that it may be possible to reduce the electron content in the sheath further by seeding the sheath with chemical additives, such as sulfur hexafloride, which are even more efficient electron absorbers than oxygen.

AFCRL hopes to demonstrate the technique on a Trailblazer rocket to be fired from Wallops Island, Virginia. This rocket, after reaching apogree, will be fired downward to simulate reentry velocities.

Mr. Daniel J. Jacavanco joined the Microwave Physics Laboratory, AFCRL in 1961 as a research electrical engineer. He received his B.S. (1960) and his M.S. (1961) in Electrical Engineering from the Lowell Technological Institute, Lowell, Massachusetts. He came to AFCRL as an Air Force lieutenant, and stayed on later as a civilian. Currently, he is engaged in research on the interaction of electromagnetic radiation with plasma. Mr. Jacavanco has about half a dozen publications to his credit.

CORRECTING IONOSPHERIC EFFECTS IN RADIO RANGING AND NAVIGATION

IONOSPHERIC PHYSICS LABORATORY, AFCRL

A radio signal transmitted through the ionosphere is slowed down, with the amount of retardation being dependent on both the signal frequency and the density of the ionosphere. This fact must be taken into account in earth-space radio ranging schemes where distance is derived by timing the signal. Ionospheric density varies with time of day, latitude and solar activity—and sometimes it varies capriciously.

If the ionospheric density is known, however, we can correct for signal retardation. Such retardation can cause errors of several hundred meters in UHF operational radars, and degrade the accuracy of geodetic satellites using UHF timing pulses. Ionospheric density is of special concern to the designers of the aircraft navigation system now under study in which VHF signals will be transmitted from two geostationary satellites to a transponder on board the aircraft and retransmitted to the satellites. From the measured time delays, the aircraft position can be located to within a fraction of a mile, assuming there are no ionospheric effects. But if the ionospheric effects are present and uncorrected, ranging errors of 10 miles or so may occur.

The ionosphere, or rather the electrons that form part of the ionosphere, imparts a corkscrew-like twist to the signal—a phenomenon known as polar-

ization twist. It is possible to determine the total ionospheric density by measuring the degree of signal polarization twist. The instrument used to make such measurements is called a polarimeter, which is nothing more than a radio receiver that processes the detected signal in a special way. A polarimeter on earth simply observes a signal originating from above the ionosphere—from a satellite, for example—and measures its polarization twist.

A markedly improved polarimeter has been developed at AFCRL by Chester Malik and John A. Klobuchar. This new polarimeter gives the capability, for the first time, of measuring the total electron content of the ionosphere on a real-time, continuous basis. It has many other distinctive capabilities. It is linear over a full 360 degrees phase range, maintains phase accuracy over a long period of time, has excellent sensitivity, and is reliable, inexpensive and easy to operate and maintain. The polarimeter requires no special RF phase-locking techniques or mechanically moving parts. It was designed from commercially available components.

The AFCRL polarimeter design is equivalent to a single rotating antenna spinning at the modulation frequency. Two orthogonal RF signals are modulated by 2 orthogonal audio frequency voltages, and the resultant signals are combined, amplified, detected and phase-compared with a signal derived from the modulating signal. The bandwidth of the modulators extends from 0.2 to 500 MHz. The modulators have been used at 30 and 137 MHz with no appreciable difference in results.

Besides its importance to ranging systems, the polarimeter could become a significant new tool for ionospheric research. By placing instruments at a number of geographic locations all over the world and observing the signals from radio stars or satellites, the total electron content of the ionosphere can be continuously monitored with high precision. Ultimately, data acquired by the instrument could yield precise models of average diurnal, seasonal and latitudinal variations of the ionosphere. Present uncertainties of ionospheric variations during magnetically active and quiet periods can also be resolved.

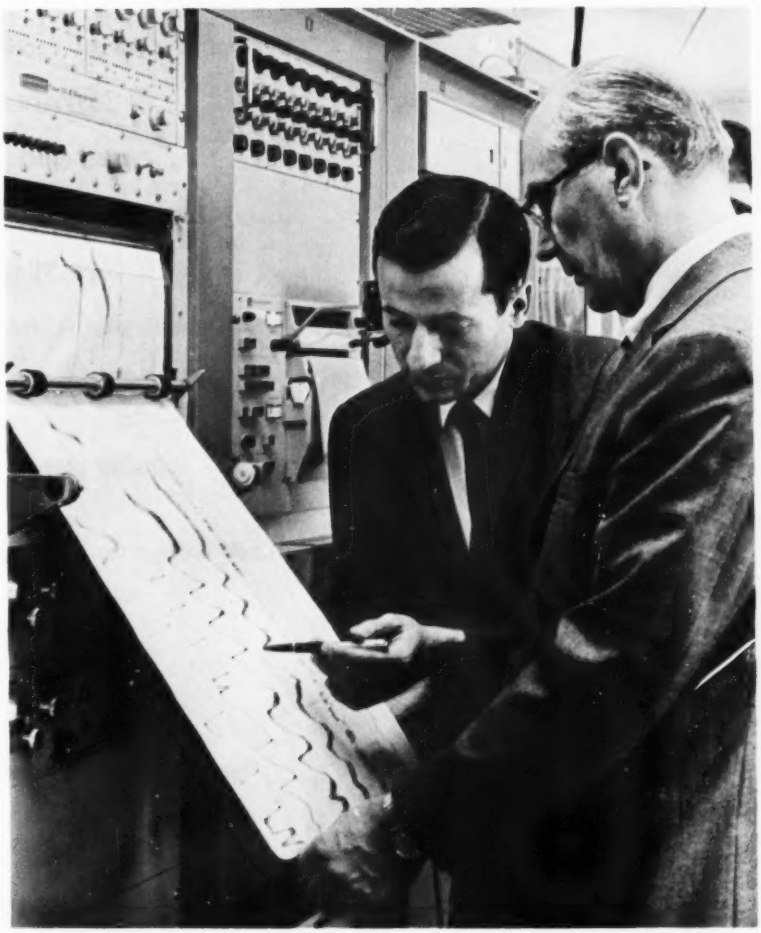
Mr. John A. Klobuchar first came to the Radio Astronomy Branch of AFCRL's Ionospheric Physics Laboratory, in 1960 as an Air Force lieutenant. After his separation from the service, he stayed on as a civilian. He received his B.S.E.E. (1958) and his M.S. (1960) from the University of Illinois. While an undergraduate, he helped to set up and operate an earth-satellite tracking station at the University of Illinois. At AFCRL he has worked extensively with lunar-reflection techniques used to determine the total electron content of the ionosphere.

Currently, Mr. Klobuchar, as a general physical scientist, is responsible for F-region total electron-content measurements to determine the effects of the ionosphere upon VHF radio waves from satellites and radio celestial sources. He is the co-designer (with Mr. Malik) of the Electron Radio Polarimeter, and is a member of the IEEE, American Geophysical Union, Research Society of America and the American Association for the Advancement of Science. He has over a dozen publications to his credit.

Mr. Chester Malik, an electronic engineer, came to the Radio Astronomy Branch of AFCRL'S Ionospheric Physics Laboratory in 1946 from the M.I.T. Radiation Laboratory. While at M.I.T., he studied special mathematics courses, and attended classes on radar at the Radiation Laboratory.

During his association with the Radiation Laboratory, Mr. Malik assisted in the production and installation of the early experimental microwave radar for the Navy and the Air Force for use in WW II. His recent work involves ionospheric research, utilizing orbiting and geostationary satellites. The results should find application to problems in communications and navigation with the use of extraterrestrial satellites.

Mr. Malik is a co-designer (with Mr. Klobuchar) of the Electron Radio Polarimeter, for which he received a $750 Scientific Achievement Award in 1969, and an Honorary plaque for the paper, "Electron Radio Polarimeter," presented at the 1969 USAF Science and Engineering Symposium. He has several publications to his credit.



Mr. John A. Klobuchar (1) and Chester Malik examine a recording of satellite signals. The recording shows fluctuations in these signals caused by the ionosphere.

TO OUR READERS

Requests for further information should be directed to the individual or laboratory of origin (except for those from Latin America).

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